PEER 9 - National Academy of Sciences

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF MAY 1, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

TTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 1, 1979

Dr. Earnest F. Gloyna, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dear Dr. Gloyna:

As part of its continuing responsibility to review criteria and guidelines for the location, design, construction, and operation of a proposed radioactive waste isolation pilot plant (WIPP), this Panel has reviewed the WIPP Draft Site Characterization Report (DSCR), SAND 78-1596, prepared by Sandia Laboratories for the Department of Energy. The DSCR, which has subsequently been published, with the same report number, as "Geological Characterization Report (WIPP)," is a compilation of the known geotechnical information about the proposed site and the surrounding region, with chapters devoted to regional geology, site geology, seismology, hydrology, geochemistry, resources, and special studies of WIPP repository rocks. It does not address such matters as socioeconomic considerations, accessibility, transportation and failure modes, which will need to be included in a complete site characterization.

The following brief account, which must be viewed in conjunction with the DSCR itself, is intended for a very limited audience of readers fully conversant with the contents of the basic document.

As a first step in this review, individual chapters of the DSCR were examined in detail by subgroups of the Panel with special expertise in the disciplinary areas involved, after which their separate comments were discussed by the full Panel in a meeting with the Sandia authors of the document.

The Panel then reviewed the extent to which the information contained in the DSCR provides sound geotechnical support for an environmental impact analysis and related decisions leading to the selection of an

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appropriate site for the proposed pilot plant. The review focused on the Report's exposition of geotechnical information with critical bearing on the site's probable ability to provide the desired long-term isolation of emplaced waste, e.g. seismic or tectonic uplift, intrusion of groundwater, thermal and mechanical characteristics of the host rock, and retardation effects along possible migration pathways. The Report did not treat, nor did the Panel consider, the effect of the emplacement of waste or the waste itself on the long term integrity of the repository. Although recognizing the considerable coverage and detail of the information presented, the Panel noted a few areas where additional data are desirable to more fully characterize the geotechnical aspects of the area under consideration. These include the following:

a) A major disagreement between conclusions reached in the DSCR and the views of R. Y. Anderson is mentioned in several places. Anderson, a professor of geology at the University of New Mexico at Albuquerque, who has specialized in the study of evaporite deposits in the Delaware Basin, was commissioned by Sandia Laboratories to prepare a report on the deep dissolution of salt in the region around the proposed WIPP site. Basing his argument on a postulated unconformity at the base of the Salado formation and on his hypothesis that the so-called "breccia pipes" are localized features of deep dissolution which originated as collapse chambers in salt beds immediately overlying the reef and basin aquifers, Anderson suggested that dissolution may be so rapid that the entire salt formation will disappear within a million years. The DSCR, on the other hand, considers only dissolution at the western edge of the salt beds and concludes that present rates will ensure preservation of the Salado at the WIPP site for at least a few million years. The Panel feels that a more thorough explanation should have been provided as to why the authors of the DSCR consider their views preferable to Anderson's hypothesis. On this same issue of salt dissolution, the DSCR estimates of the rate of retreat of the solution front two or three miles west of the site are evidently based on the assumption of uniform dissolution over a wide area under average conditions. A rational basis should be provided for this assumption, vis a vis the possibility of accelerated dissolution rates in local areas, with selective removal of salt from beneath the present sedimentary cover, particularly if pluvial conditions were to change in the future.

b) Additional data and analyses would be helpful to determine with greater confidence the current rates of tectonic uplift in the region and whether, as a result, the salt may be exposed to accelerated erosion at some time in the foreseeable future.

c) The so-called "breccia pipes" need more detailed analyses to determine whether they may serve as conduits for water that may have promoted, or may in the future promote, deep dissolution of the salt beds.

d) There appears to be sufficient information to resolve the question regarding the likelihood of upward flow from the Bell Canyon formation through the Salado, where the proposed repository horizons are located, to the overlying Rustler. This should be addressed.

e) Because rock properties have a strong influence on mine design, more detailed information is needed on the various rock types in the area and on their permeability, fracture, and thermal properties under conditions as similar as possible to those that would be found in a repository. Both laboratory and field tests approximating in-situ conditions will be required to develop this information.

f) The information on sorption of the important radionuclides by materials to be expected in possible migration paths, under conditions resembling those near a possible repository, seems to be sparse. As soon as the types of waste to be stored in the repository are known, a more complete discussion should be presented of the retardation anticipated in the migration paths.

g) The most recent episode of any recrystallization in the Salado formation near the proposed WIPP site is reported to have occurred about 200 million years ago. The Panel urges confirmation of this important date by further studies and other techniques, as described in Section 7.8 of the DSCR.

In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objectives, criteria for safe operation, and waste forms to be accommodated.

Sincerely,

Frank L. Parker

Frank L. Parker, Chairman
Panel on the Waste Isolation
Pilot Plant

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF SEPTEMBER 10, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 10, 1979

Dr. E. Bright Wilson, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Wilson:

During the past year, the Panel on the Waste Isolation Pilot Plant (WIPP) has become familiar with the findings of the various extensive geological explorations, including boreholes from the surface and attendant geotechnical studies, attempting to characterize the proposed WIPP site and provide a basis for judging this aspect of the site's suitability for a waste repository. This familiarization process has included briefings by representatives of Sandia Laboratories and the U. S. Geological Survey, study of both the published and unpublished technical literature, site visits, examination of actual borehole cores, and discussions with other experts in selected geotechnical areas.

Our efforts have brought to light no disqualifying results from these explorations and studies to rule out further consideration of the proposed site at this stage. The Panel has reached this conclusion after taking into account the comments made in my letter of May 1, 1979, reporting on our review of the WIPP Draft Site Characterization Report (issued as SAND78-1596, Geological Characterization Report), pointing out that certain effects have been observed which can be interpreted as indicating the possible existence of significant anomalies. Additional information is clearly required before these anomalies can be resolved

and a decision made regarding the adequacy of the proposed WIPP site for the construction of a repository. Furthermore, continued commitments to final details of repository design in the absence of additional site-specific information may be both misleading and wasteful.

The Panel is of the unanimous opinion that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and cannot resolve all the major remaining uncertainties. Accordingly, the Panel recommends that:

(1) An exploratory shaft be sunk at the site of one of the proposed access shafts as soon as practicable, to the depth of the proposed repository horizon.

(2) Drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

Development of the shaft, tunnels, and any other exploratory excavations should be consistent with applicable environmental and safety standards, strict quality assurance procedures, and should be compatible with an actual repository, if one is constructed at this site.

Sincerely,

Frank L. Parker

Frank L. Parker
Chairman, Panel on the
Waste Isolation Pilot Plant

NATIONAL ACADEMY OF SCIENCES

CONTINUING EVALUATION OF THE CARLSBAD SITE

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Report No. DOE/CH/93023-1

CONTINUING EVALUATION OF THE CARLSBAD SITE

A Report to the U. S. Department of Energy, prepared by the Panel on the Waste Isolation Pilot Plant of the Committee on Radioactive Waste Management.

COMMISSION ON NATURAL RESOURCES
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
July 28, 1980

ABSTRACT

It is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements, set forth in his February 12, 1980, message to the Congress, for evaluation of this site as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

NOTICE: The project that is the subject of this report was authorized by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Such authorization reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

The report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee of the National Academy of Sciences.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

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NOTE: Two Panel members did not participate in the deliberations leading to this report; John W. Winchester was out of the country on sabbatical leave, and Karl P. Cohen is a new member of the Panel.

CONTINUING EVALUATION

OF THE CARLSBAD SITE

The Panel on the Waste Isolation Pilot Plant (WIPP) was organized by the National Academy of Sciences in 1978, under the Committee on Radioactive Waste Management of the National Research Council, to review the scientific and technical criteria and guidelines for designing, constructing, and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere, with specific attention to a proposed site near Carlsbad, New Mexico.

On February 12, 1980, President Carter transmitted to the Congress "A Report on His Proposals for a Comprehensive Radioactive Waste Management Program." This report states the President's decision that the WIPP project, currently authorized for the unlicensed disposal of defense transuranic waste and for research and development using high-level defense waste, should be cancelled; but that the Carlsbad site will continue to be evaluated, along with other sites in other locations, for possible use as a licensed repository for defense and commercial high-level wastes.

The Panel has reviewed in depth the work of the DOE contractors on the geologic characteristics of the Carlsbad site, the characteristics of the defense and spent-fuel radioactive wastes that have been considered for emplacement, and the conceptual design of the repository. The WIPP Draft Environmental Impact Statement has been analyzed with

respect to the potential impact on public health and safety.

As a result of these deliberations, the Panel has previously concluded that continued investigation of the Carlsbad site is warranted and has recommended that the project proceed with an exploratory shaft to determine in greater detail the geologic, hydrologic, and structural features of the candidate salt beds, and with in-situ tests as necessary to evaluate the geotechnic adequacy of this site for a waste repository. The Panel considers these in-situ tests to be no less timely and technically desirable within the framework of the President's statement.

In connection with the Carlsbad site, a talented team of scientists and engineers has been assembled, and extensive geological exploration has been conducted. Laboratory facilities are excellent, important experiments on waste disposal are under way, and underground engineering designs have been developed. The project has gained momentum that would be difficult to recapture if it were to be interrupted. There are sound technical reasons for continuing the exploratory work:

1. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

   The analyses made thus far, supported by ongoing and planned testing programs to validate these analyses,

lead to the reasonable expectation that the site may be suitable not only for its original limited purpose as a defense transuranic waste repository but also as a licensed repository for both defense and commercial high-level and transuranic waste. The present experimental program will yield results that can be applied to the expanded purpose envisioned in the President's program. The exploratory shaft, now planned and ready to be constructed to a depth suitable for transuranic waste, can be extended to a lower horizon, where there is another salt bed that may be better suited for high-level wastes. The information obtained from this exploratory work will not only be useful for further evaluation of the Carlsbad site but can also be applied to other candidate salt formations.

2. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives.

- Very long lead times are involved in the President's proposed new program of selecting alternative sites, constructing test facilities at each, choosing a first repository site, and eventually constructing one or more licensed repositories.

  The extensive information already obtained on the Carlsbad site and the demonstrated expertise of the existing investigative teams provide an

opportunity to proceed much sooner with in-situ testing at a potential candidate site--a capability which will have to be developed before this or any other site can be selected for a first actual repository.

More is known about the Carlsbad site than about any of the other sites under consideration. Questions remain that will require resolution by additional analyses and testing, but such questions are normal for this stage of an investigation.

The Panel concludes that it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:

- providing prototype experience in site qualification;
- testing, in situ, performance assumptions about the geologic medium; and
- developing techniques and information which will be required in the licensing process.

If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review.

NATIONAL ACADEMY OF SCIENCES

PROGRESS REPORT: JULY 1, 1978 TO DECEMBER 31, 1979

DOE/NE/93023-2

REVIEW OF THE CRITERIA FOR THE SITE SUITABILITY, DESIGN, CONSTRUCTION, AND OPERATION OF THE PROPOSED WASTE ISOLATION PILOT PLANT (WIPP)

PROGRESS REPORT: JULY 1, 1978, to DECEMBER 31, 1979

Prepared for
the U.S. Department of Energy
under Task Agreement No. DE-AT01-76NE93023

PANEL ON THE WASTE ISOLATION PILOT PLANT

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

COMMISSION ON NATURAL RESOURCES

NATIONAL RESEARCH COUNCIL

WASHINGTON, D.C. SEPTEMBER 1981

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In March 1978, the Department of Energy (DOE) asked the National Research Council "to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere." The National Research Council assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources. The Committee organized the Panel on the Waste Isolation Pilot Plant to "review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations, viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

In July 1978, when this study began, the Waste Isolation Pilot Plant (WIPP) was to be a mined repository in bedded salt in Eddy County, New Mexico, for the disposal of transuranic (TRU) waste, with experimental facilities for studying the interactions of high-level waste with the host rocks. At that time, though not officially part of the project mission, DOE was also considering use of this repository for disposal of a limited number of commercial spent fuel elements as an alternative waste form. This option was discussed frequently in technical briefings of the Panel and in supporting documentation. The Panel has examined some of the generic issues related to this possible course of action, as well as those concerns raised solely by the proposed disposal of transuranic waste in the particular salt formations at the WIPP site.

This report recounts the Panel's findings through the end of 1979--the first half of the originally contemplated three-year study. By that time, several major program documents had been issued and examined by the Panel, including the Geological Characterization Report (Sandia Laboratories 1978), the Title I Design Report (Bechtel National, Inc. 1979), and the Draft Environmental Impact Statement (U.S. DOE 1979). This report is based on analysis of the contents of these and other documents, numerous technical briefings, extensive discussions with representatives of DOE and its contractors, and several field visits.

Not all of the views expressed herein are currently pertinent. During 1980 and early 1981, following the period covered by this report, the WIPP project experienced major changes in direction and scope, as well as varying degrees of administrative certainty regarding its future. Many of the technical deficiencies that were perceived to exist at the end of 1979 have since been remedied by additional investigations and design changes. During 1980, a Final Environmental Impact Statement, a Safety Analysis Report, and a Revised Title I Design have been issued, and work has now begun on the Site and Preliminary Design Validation Program. Evaluation of these more recent efforts, in the context of the currently defined mission of WIPP as a repository for defense-originated TRU waste only, is a matter for future deliberation by the Panel.

CHAPTER 1

INTRODUCTION AND BACKGROUND

The history of the Waste Isolation Pilot Plant (WIPP) project was presented to this Panel at a study planning session on June 5, 1978. As far back as March 1974, the Oak Ridge National Laboratory had begun site investigations for a terminal radioactive waste repository in a region selected by the U.S. Geological Survey in the Los Medanos area of New Mexico. In May of that year, this work was suspended in favor of the concept of retrievable surface storage, and the land-withdrawal action that had been initiated was deferred in December 1974. The Albuquerque Operations Office of the U.S. Atomic Energy Commission (AEC) and the Sandia Laboratories were then requested by AEC headquarters to become involved in the program to locate a site for a radioactive waste disposal pilot plant for defense low- and intermediate-level transuranic waste, with some provisions for experimentation with high-level waste. When drilling began at the Los Medanos region in 1975, unanticipated subsurface geological conditions were found, including high-pressure brines and gases. Consequently, the first drilling site was rejected, and the U.S. Geological Survey and Sandia recommended a new site 7 mi (11.2 km) to the southwest. The general location of the site and a geologic section through the Los Medanos area are shown in Figures 1.1 and 1.2, respectively. In January 1976, the geological investigations were resumed at the newly proposed site, and the project was given its present name: Waste Isolation Pilot Plant.

The drilling of ERDA 9, the first hole at the new site, commenced in April 1976. In October 1976, funding was requested for an architect-engineer, and a new land-withdrawal notice was placed in the <u>Federal Register</u> in December 1976. In April 1977, a preliminary version of the Draft Environmental Impact Statement was distributed by the Department of Energy (DOE) for comment, and it was announced that WIPP would be a licensed facility. In June, the final version of the conceptual design was issued. In September, Bechtel was selected as the architect-engineer, and in November, the DOE sent a letter to the Nuclear Regulatory Commission saying they intended to request a license.

In February 1978, the "Deutch Report" (U.S. DOE 1978) called for a demonstration of the experimental emplacement of high-level waste and possibly ultimate disposal of commercial spent fuel at the WIPP site. Objections were raised by the U.S. House Armed Services Committee,

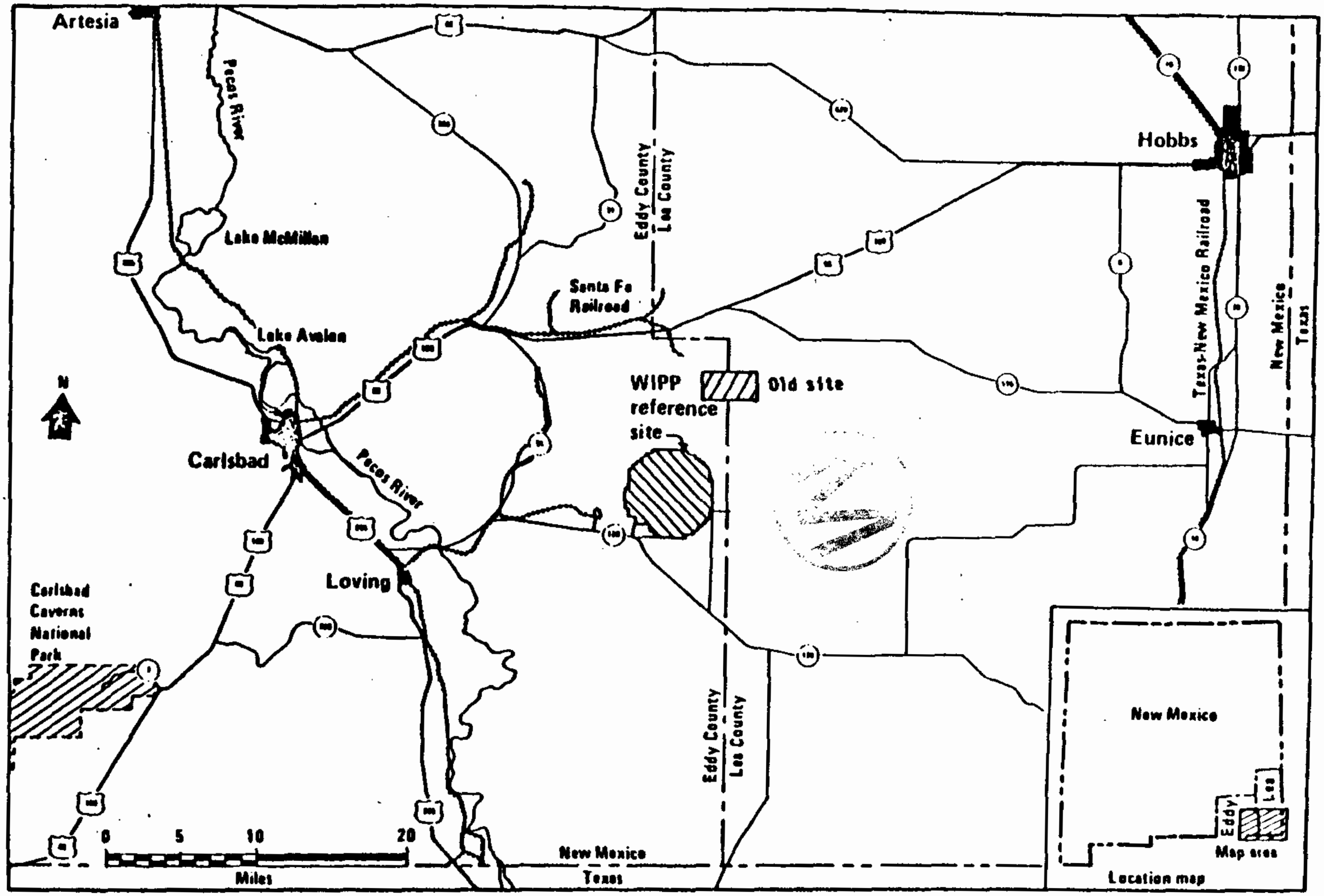

FIGURE 1.1. General location of the WIPP site.
SOURCE: U.S. Department of Energy (1979).

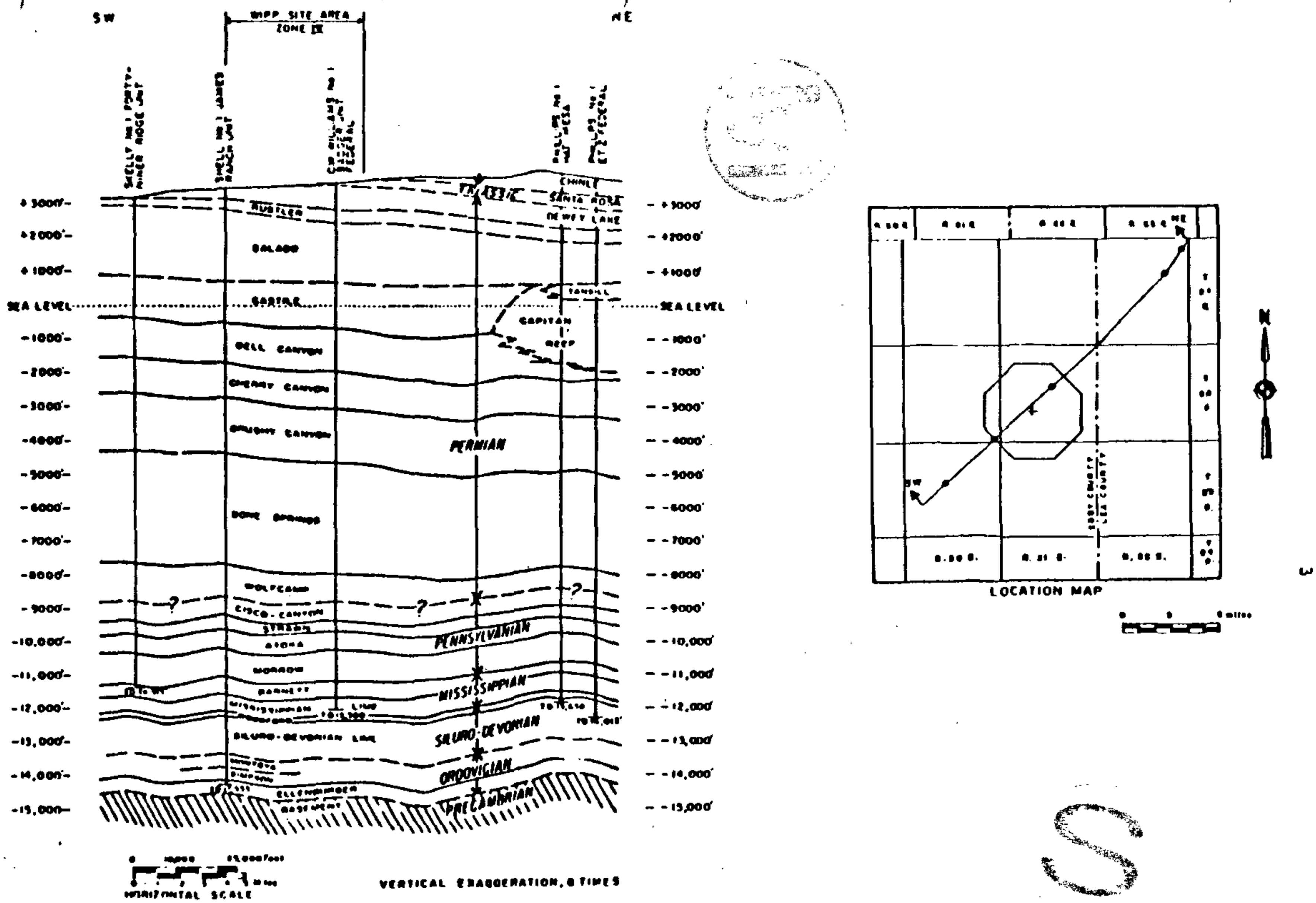

FIGURE 1.2. Generalized site stratigraphic section.
SOURCE: Sandia Laboratories (1979); after Netherland, Sewell and Associates (1974).

which held that the site should be unlicensed and used only for defense waste.

The Geological Characterization Report (Sandia Laboratories 1978), a compilation of geotechnical information available as of August 1978 and judged to be relevant to WIPP studies, was published in December 1978.

In March 1979, an Inter-Agency Review Group (IRG) appointed by President Carter reported (IRG 1979) on its review of the progress of the U.S. waste disposal program and suggested four alternative technical strategies, one of which would specify salt as the host geologic medium for the first mined repository. The following month, the WIPP Draft Environmental Impact Statement, or DEIS (U.S. DOE 1979), including consideration of the possibility of disposal of limited quantities of commercial spent fuel, was issued for public comment. As of the end of 1979, no decision had been made among the several options suggested by the IRG, and the DEIS was still undergoing public review and comment.

Independently of this DOE-sponsored study by the National Research Council, the state of New Mexico itself has set up four groups concerned with WIPP--an Environmental Evaluation Group (EEG); a Radioactive Waste Consultation Task Force, composed of three members of the governor's cabinet; a Radioactive Waste Consultation Committee, composed of eight members of the state legislature, and a Governor's Advisory Committee on WIPP.

WIPP program activities were in progress during the course of this study; thus the Panel was evaluating existing data and concepts while new information was being obtained and analyzed. This report is not a summary of WIPP activities, but an analytical commentary on those aspects that the Panel reviewed through the end of 1979. For completeness, material has been included that was incorporated previously in two letter reports (Appendixes A and B) that dealt with the suitability of the site from a geological and hydrological standpoint and the limitations of surface exploration of underground formations.

CHAPTER 2

SITE SELECTION CRITERIA

The criteria used in selecting the WIPP site include the generic criteria commonly cited in proposals for waste isolation in bedded salt (National Research Council 1970, 1978) and seem technically and scientifically adequate. They require (1) a bed of rock salt (halite) at least 60 m thick, as pure as possible, to minimize complications from brine of complex composition and from water released from hydrous minerals; (2) a depth greater than 300 m to ensure freedom from surface influences; (3) a depth less than 1,000 m to ensure acceptable creep rates in the salt; (4) approximate horizontality to minimize difficulty in mining operations; (5) little indication of recent tectonic or igneous activity; (6) sufficient distance from an exposed edge or underground aquifer where salt dissolution is occurring; and (7) an area without sizable economic resources.

Two additional criteria specific to the Carlsbad area were suggested by previous experience at Lyons, Kansas (Bradshaw and McClain 1971) and at an earlier WIPP site mentioned in the DEIS: location of the repository at least 1.6 km from the nearest borehole penetrating as deep as the selected beds, and at least 8 km from the Capitan Reef, to avoid a zone of disturbed bedding known to parallel the reef.

With these criteria in mind, lines were drawn on a map to outline areas where salt beds of requisite thickness at proper depths were known to occur and to exclude areas within 1.6 km of known deep boreholes, within 8 km of the Capitan Reef, within 1.6 km of the dissolution front, or with known potash or hydrocarbon resources. Two areas of reasonable size outside these lines were identified (see Figure 2.1). One seemed less suitable because it had deeper salt beds and was closer to an oil field where water flooding may be used for secondary recovery in the future. Both sites have the advantages of nearly flat topography, an arid climate, and sparse population. The major regional geologic structures in the vicinity are shown in Figure 2.2.

Although the generic criteria as applied to the WIPP site are in considerable measure satisfied, questions about three of them have not been completely answered. Most troublesome of the three is the problem of economic resources: recent evaluation of resources during site characterization indicates the likely presence of economically significant quantities of potash and natural gas at the site. Because

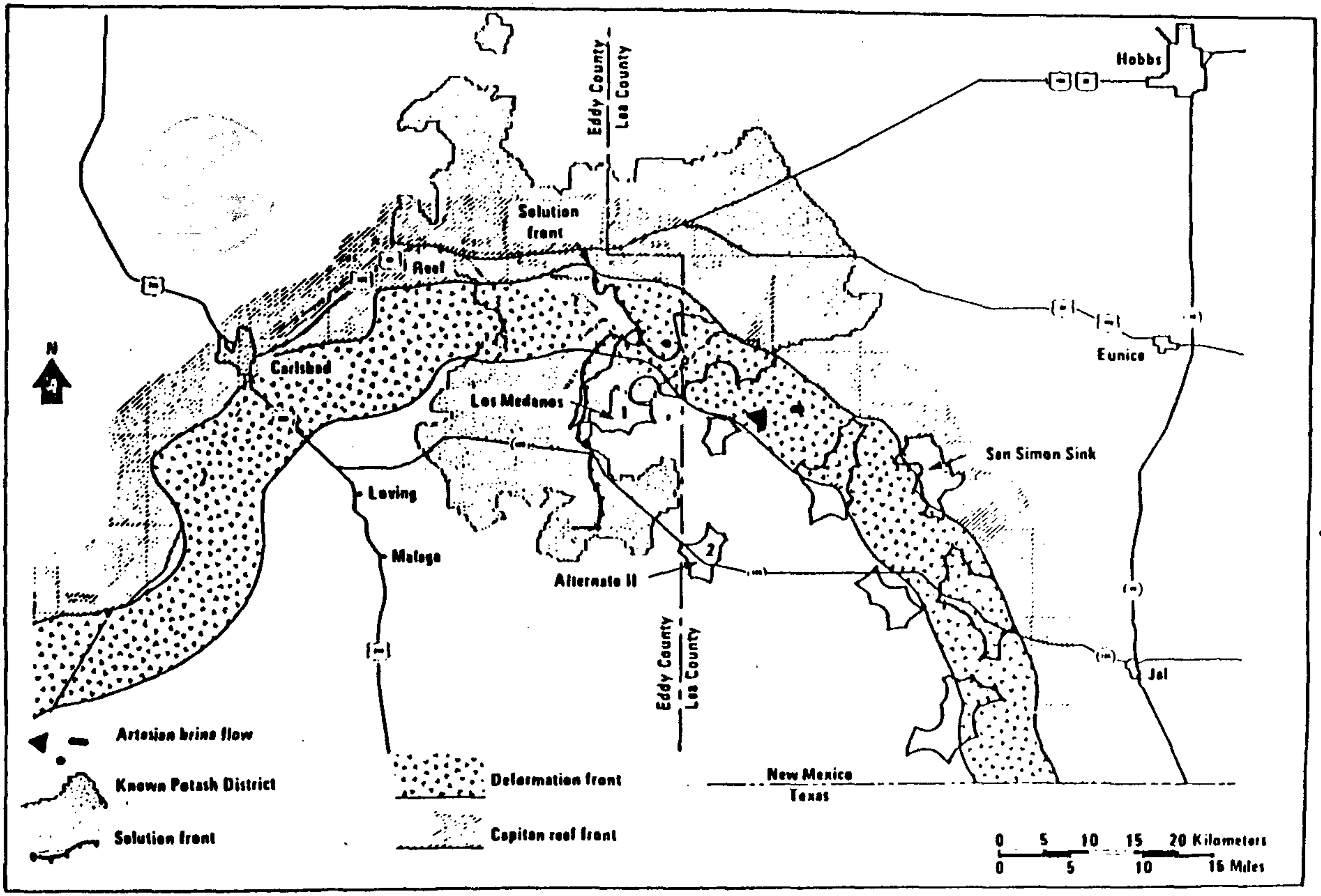

FIGURE 2.1. Application of the site selection criteria.
SOURCE: U.S. Department of Energy (1979).

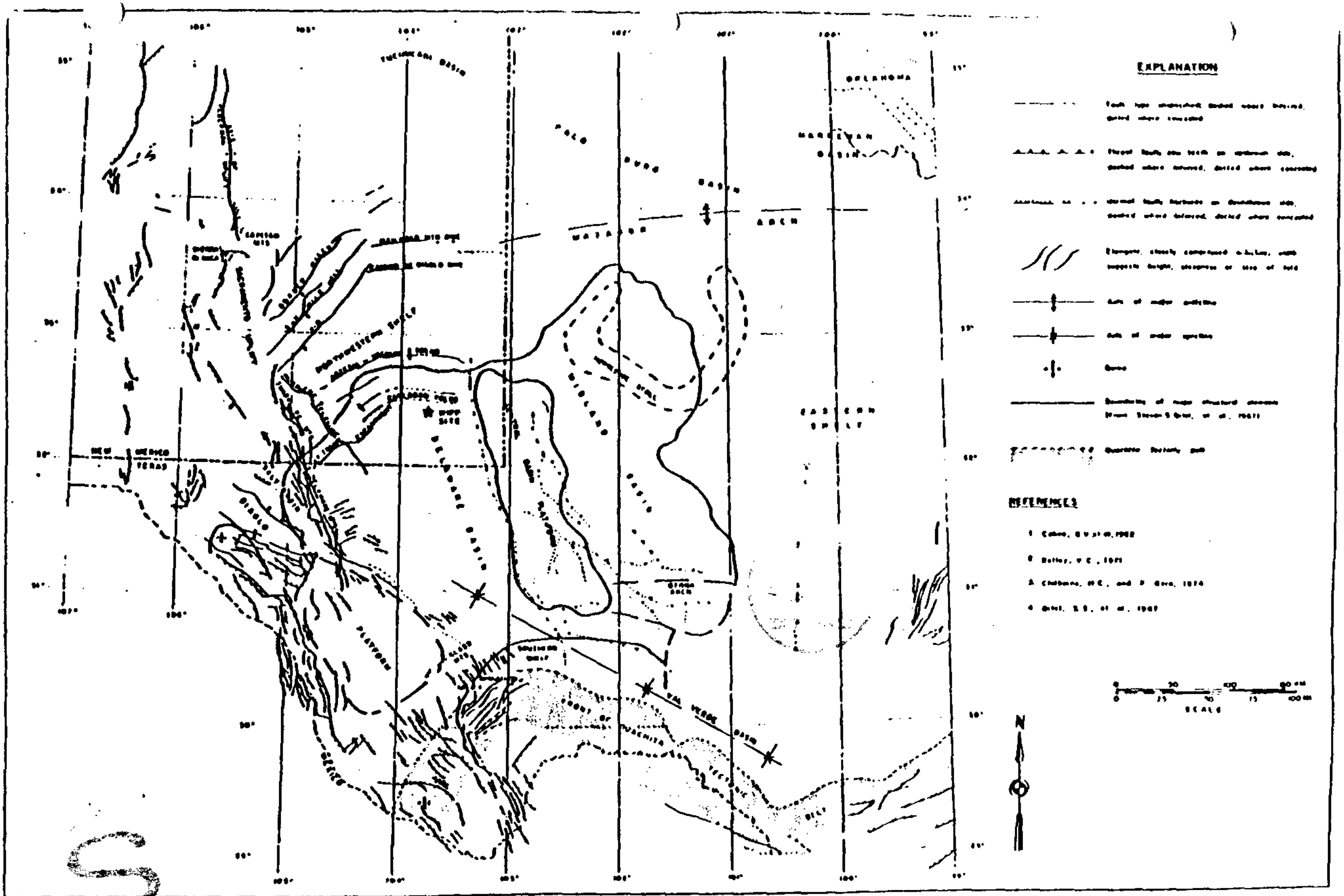

FIGURE 2.2. Major regional structures in the vicinity of the WIPP site.
SOURCE: Sandia Laboratories (1978).

the potash deposit is 400 to 800 ft (120 to 240 m) above the proposed repository horizons, it could probably be mined without disturbing a repository beneath. The natural gas is below the repository beds and could probably be tapped by angle drilling. The existence of the potash and hydrocarbons means that the criterion specifying minimal conflict with natural resources may not be satisfied; but the possibility of recovering both materials without jeopardizing a repository site implies that acceptability of the site is not necessarily compromised. Further study is needed for a decision as to whether recovery of the potash and hydrocarbons must precede construction of a repository, in which case government subsidy of the operation would be needed, or whether recovery could be safely deferred to a later date, after the repository is completed, when the value of the resources might be greater or less and their exploitation might be more or less economically attractive.

A second unresolved question concerns the possibility of salt dissolution by upward-moving water from aquifers below the salt beds. If the dissolution were concentrated in isolated fissures in the underlying beds, fluid circulation might be set up that would lead to active dissolution of the salt in small areas and possible subsequent collapse of the overlying salt beds. This hypothetical mechanism is a possible explanation for the vertical pipe-like masses of broken rock, the so-called "breccia pipes," that have been found in a few places in this region. The number and significance of these features remain conjectural. The pipes are difficult to recognize in geologic mapping at the surface, because their outcrops are easily confused with local areas of breccia formed by near-surface dissolution of evaporite and carbonate minerals. All the drilling done through 1979 has identified only three pipes, and these are all over the Capitan Reef or its back reef facies, which are prolific aquifers. Despite extensive potash mining in the Delaware Basin, only a single pipe has so far been encountered underground. Because no pipes are recognized or suspected at the WIPP site, and because no certain evidence of present-day pipe-forming activity has been reported elsewhere in the region, the chance of damage to a waste repository from this source seems small. The effects of such a connection are discussed in Chapter 5.

Nevertheless, either the presence of an old, inactive pipe in an area being considered as a repository site or the formation of a pipe during or after repository construction could have consequences serious enough to require attention. The danger from an inactive pipe is the possibility that the fractured material in the pipe itself, or the disturbed salt beds near the pipe, might be more permeable than the surrounding salt and could thus serve as a conduit for groundwater movement into or away from a repository. No evidence of greater permeability has been reported in or near the pipes examined to the end of 1979, and the areas of disturbed beds caused by pipe formation are limited to zones a few tens of meters in diameter. Hence inactive pipes beyond the periphery of the WIPP site would not jeopardize a repository, and a pipe within the site could be avoided in repository construction; but the possibility of more permeable material in a pipe is great enough that pipes within the site should be located and carefully studied. The danger from formation of a new pipe is the obvious one that collapse of salt beds beneath a repository as the pipe works its way upward would open the site to inflow of groundwater. Any evidence for present-day pipe-forming activity would therefore be important, even though such activity at a distance of several kilometers from the WIPP site would not constitute a direct threat to repository integrity.

The distribution of existing pipes in and near the WIPP site can be determined by horizontal drilling into the Salado beds from the base of an exploratory shaft and by drilling from the surface in places where rock structure or topography gives an indication of disturbance that might be caused by breccia pipes beneath. Present breccia-forming activity, if it exists, would presumably show itself by areas of subsidence at the land surface, such as San Simón sink; drilling into such areas could demonstrate whether the subsidence actually results from breccia formation at depth. Furthermore, any deep dissolution that may be occurring would probably be concentrated along zones of fracturing, and such zones may betray themselves on LANDSAT imagery. Mapping of lineaments from the images could be used to guide additional drilling. Such mapping would be useful also in locating places where nearer-surface groundwater flow may be concentrated, particularly in aquifers in the Rustler formation.

Further study of the nature and distribution of breccia pipes is obviously desirable, but how extensive the study should be is not clear. Certainly all scientific questions about these structures need not be answered for purposes of site characterization. A consequence analysis of the possible effects of breccia pipes is needed and is in fact being planned by Sandia scientists (as of the end of 1979). Preparatory to this analysis a program to characterize existing pipes is under way, with respect to porosity, deformation of adjacent beds, movement of hydrocarbons, and probable age. When this program is completed a decision should be possible as to whether the hazard to a repository posed by existing or potential future pipes is sufficient to warrant fuller investigation.

Two additional possible problems are (1) the pockets of pressurized brine that are known to be present in the Castile formation and could be present in the Salado and (2) the thin layers of breccia, possibly formed by widespread subsurface dissolution within the salt beds, that have been noted in a few drill cores from boreholes outside the WIPP site (Anderson 1980). A large brine pocket would indeed be a major hazard to workmen if it were penetrated unexpectedly during excavation of a repository, but the pockets can be located in advance of construction by exploratory drilling or geophysical techniques and can be drained by well-known engineering procedures. Interpretation of the breccia beds is controversial, but no confirmatory evidence for extensive interbed dissolution has been suggested except near the salt edge on the west side of the basin. Neither breccia beds nor brine pockets appear to constitute a serious problem on the basis of present knowledge, but their significance can be better evaluated when subsurface exploration is undertaken.

Dissolution at the salt edge west of the WIPP site has been in progress for a long time, and of course is continuing today. The maximum rate of lateral retreat, estimated from the conservative assumption that the Salado formation extended to the Capitan Reef on the eastern edge of the basin at the end of Ogallala time, is 6 to 8 mi (9.6 to 12.8 km) per million years. The rate of vertical lowering of the salt by dissolution has been estimated (from rates of brine discharge into the Pecos River and streams east of the basin) at 330 to 500 ft (100 to 150 m) per million years. Since the Rustler-Salado contact where dissolution is active at present lies 2 mi (3.2 km) west of the center of the WIPP site, a repository at a depth of 1500 ft (450 m) below this contact would not be jeopardized by salt dissolution for at least a few million years.

The possibility of rapid dissolution along particular zones in the salt should be explored, however, to make sure that the rate of retreat of the front through the long future is adequately represented by extrapolation of average values. Such exploration (which is currently in progress) will require detailed surface mapping, supplemented by trenching and shallow drillholes. The probability of local dissolution rates greatly exceeding the average is so remote, however, that the sinking of an exploratory shaft should not be delayed on this account.

The third criterion that has recently been called into question is the tectonic stability of the region in which the WIPP site is located. Because fault movement and eruptions of basalt are known to have occurred in the Rio Grande valley 250 km west of the site during the past few million years, because recent faulting has occurred at the salt graben 70 km west of the site, and because precise leveling has shown evidence of continued slow displacement of rocks underlying the valley, the WIPP site is thought by some to be in jeopardy. It is even speculated that fault motion might be occurring today beneath the salt beds, not noticeable at the surface because the motion would be taken up by plastic deformation in the salt. Considerable distance separates the WIPP site from the Rio Grande valley, however, and there is neither seismic evidence for significant crustal movement near the site nor geologic evidence for tectonic disturbance or volcanic activity during the past several million years. The faults and lava flows in the Rio Grande valley have been known for a long time and were critically considered when the WIPP site was chosen; recent work has added no convincing new evidence for tectonic effects at this distance from the valley.

Because there is no evidence of tectonic effects of any magnitude and because minor tectonic disturbance, in any event, would not significantly damage a well-engineered repository, the Panel thinks that the site satisfies the criterion of tectonic stability. Additional evidence regarding tectonic activity is desirable, of course, and measurements to provide such evidence are under way. The criterion of tectonic stability seems so well satisfied, however, that these measurements should not be cause for postponing underground exploration.

Through 1979, study of the WIPP site has been limited to geologic mapping and geophysical measurements at the surface, examination of boreholes and drill cores, and laboratory experiments on salt samples. Assurance that the salt beds do not have structures that might complicate repository construction or serve as channels for groundwater movements--faults, anticlinal folds, shale interbeds, breccia pipes--has been provided only by such surface observations. Further work of this sort is still needed, particularly to provide data on the number and nature of breccia pipes in the vicinity and on details of dissolution at the salt edge. In many respects, however, exploration from the surface has been so complete and so detailed that it has reached a point of diminishing returns, not to mention the risk to the integrity of a future repository that could result from additional deep boreholes. Even if long continued, these efforts are unlikely to provide the critical evidence regarding details of the physical and chemical characteristics of the candidate salt beds that will be needed for a decision as to whether the site is or is not suitable for a repository. This kind of evidence can be obtained only by study of the salt in place, which requires sinking a shaft and exploring the salt bed or beds by tunnels and horizontal drilling.

In summary, study of the WIPP site and its environs has shown that the criteria for site selection were in considerable measure satisfied; the Panel thinks probable site suitability has been demonstrated sufficiently to justify the sinking of an exploratory shaft without delay, as was recommended in the letter attached as Appendix B.

CHAPTER 3

DESIGN OF UNDERGROUND FACILITIES

Once a suitable site for an underground nuclear waste repository has been selected, one of the most important factors--if not the most important one--contributing to the successful use of deep underground excavations for the disposal of radioactive waste is the design and construction of the excavations that constitute the repository. Unfortunately, the initial conceptual repository designs of which the Panel is aware, including the design proposed for the WIPP site, reveal neither a clear understanding nor recognition of the important difference between a mine and a repository. Mining engineering provides a wealth of experience related to the design and construction of a repository, but the function of a repository is very different from that of a mine. The principal objective in mining is to remove as much of the ore as is practicable, consistent with short-term safety. The principal objective in making repository excavations is to disturb the geologic media as little as is practicable, so as to ensure long-term safety and isolation.

The WIPP repository has already progressed to the stage of preliminary (Title I) design. According to DOE definitions, Title I design ". . . utilizes the conceptual design and design criteria that have been prepared for the project as design bases." It involves the refinement of descriptive information and the development of more detailed outline specifications that will serve as the firm basis for definitive (Title II) design. The Title I Design Report by Bechtel National, Inc. (1979) reveals concepts and details that raise questions concerning design safety and adequacy.

Adequate conceptual design of an underground repository requires recognition that the properties of a geologic medium, even salt, are unlikely to be uniformly satisfactory over dimensions of interest and that many variations in the properties and structure of the salt at the depth of the repository will be revealed only as the excavations are made. Some of these variations may lead to unexpected difficulties or may adversely affect the ability of the salt or the overlying strata to isolate the wastes from the biosphere. Accordingly, it may prove desirable to be able to treat some portions of the repository differently from others and perhaps even exclude some portions of the site from use for the disposal of waste.

For these reasons, and to limit the extent of any accidents that may occur prior to final sealing of the repository, such as the intersection of a major brine reservoir or the outbreak of a fire, the repository should be laid out as a number (say, four to six) of independent modules. Substantial barriers of undisturbed salt should be left between modules, to ensure that each module is isolated effectively from every other module. As few accessways as necessary for safe development of a module should penetrate these barriers, and each accessway should be provided with a bulkhead, which can be closed quickly at either end of the barrier. Ultimately, these accessways must be sealed permanently with a fill having low porosity and permeability.

As shown in Figure 3.1, the original Title I design [note: changes in this design made since the end of 1979 should be reviewed by the Panel in its subsequent deliberations] showed the repository essentially as sets of four rooms 32 ft (9.7 m) wide, separated by support pillars 25 ft (7.6 m) wide, and separated from adjacent sets of rooms and pillars by abutment pillars 360 ft (109 m) wide, penetrated at intervals of 268 ft (81.2 m) by crosscuts. This design gives an overall extraction ratio of about 26 percent. Kaiser Engineers, Inc., note that "A room with a central pillar is not favored because high extraction ratio is counterproductive for a repository, where safety is reduced and cost increased as extraction is increased" (Watson et al. 1979).

This original Title I design incorporated a degree of modular design through the use of the large abutment pillars, but the integrity of the pillars was destroyed partially by the crosscuts. The Panel was advised that these crosscuts would be closed by bulkheads at each end and that, finally, the space between bulkheads would be sealed by filling each crosscut, in an endeavor to restore the integrity of the abutment as a whole. The original Title I drawings, however, show that these crosscuts are to be used for the disposal of waste. The isolation that would be provided by the bulkheads in the event of fire, flooding, or leakage of waste is questionable, and thus even the modest degree of modularization in the original design is compromised. The Panel is convinced that truly modular repository design would make better provision for geological variations and would provide more inherent safety, by preventing accidents or failures in one part of the repository from spreading throughout the repository.

A well-established rule of thumb from wide mining experience is that adjacent excavations should occupy less than a third of the plan area if there is to be no adverse interaction between them. Figure 3.2 was prepared by Serata (1978) of Serata Geomechanics, Inc., consultants to Bechtel on the design of the underground excavations at the WIPP facility who have a wealth of experience in evaporite mining. The figure illustrates the interaction between two adjacent circular cavities in weak and strong salt at various depths as a function of the ratio of their separation to their diameter. From this figure it is clear that this ratio must be greater than 4 to preclude excessive interaction. Serata claims that at ratios of less than unity the plastic deformation of the salt between cavities is stable, but it

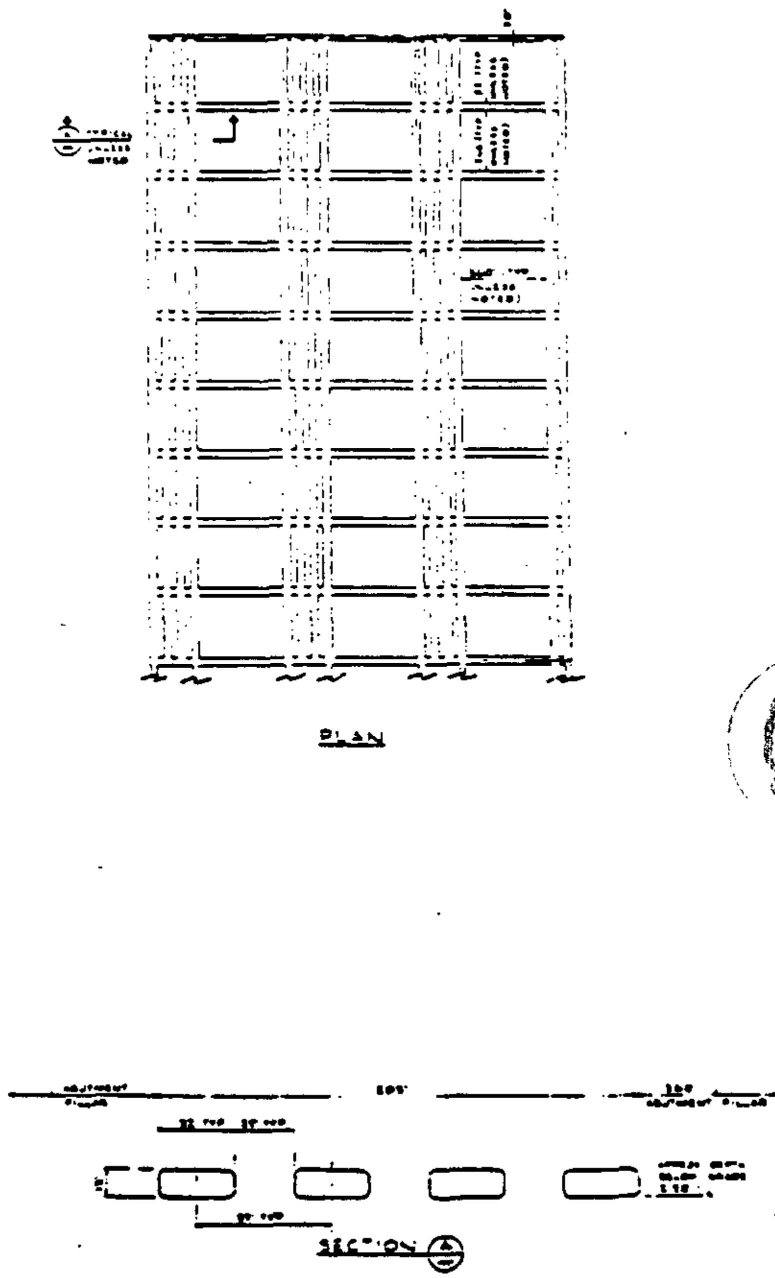

FIGURE 3.1. Repository room design.
SOURCE: Bechtel National, Inc. (1979).

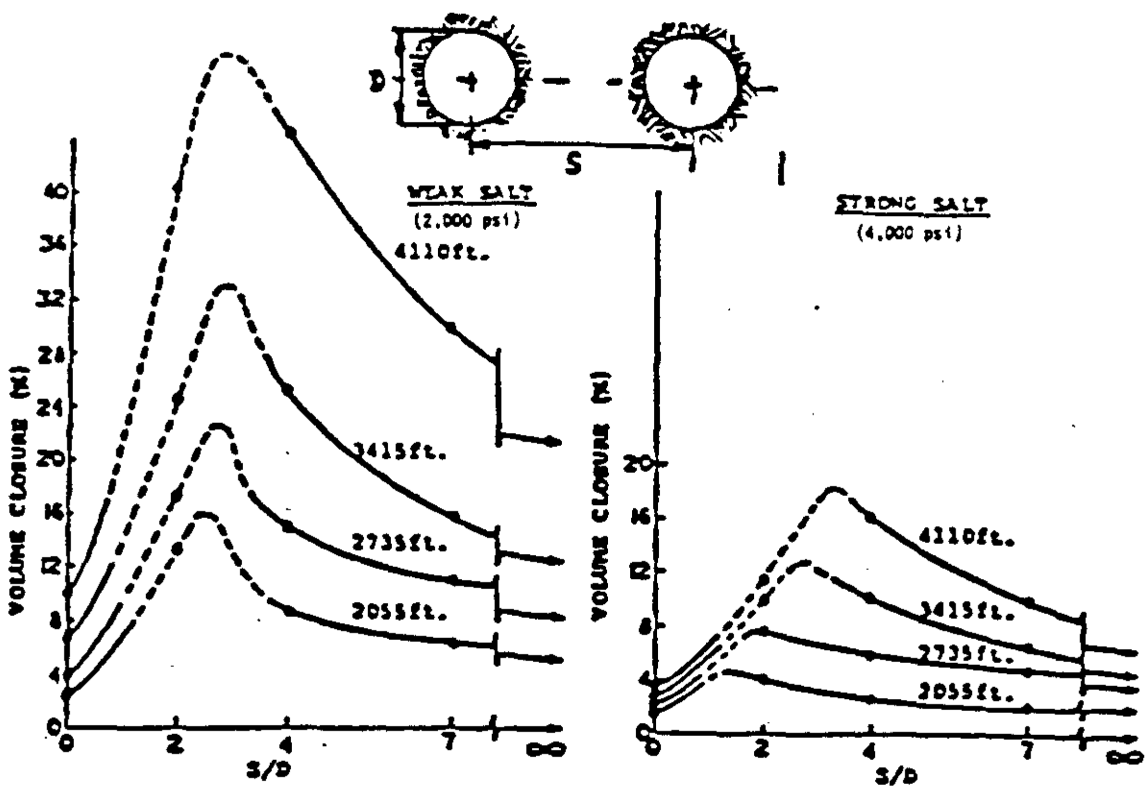

FIGURE 3.2. Critical separation distance of double cavities at various depths.
SOURCE: Serata (1978).

would seem to be most imprudent to design a radioactive waste repository, especially an early repository, in such a way that there was any question whatsoever about the behavior and stability of the salt between the excavations.

If the above arguments and evidence are accepted, the ratio of the center-line spacing of the cavities to the cavity diameter in the Title I design is much too small. Interaction between these excavations must be expected, and no one can be sure that it will not impair the safety and stability of these excavations. Accordingly, on the basis of much experience and Serata's data, the Panel believes strongly that the "separation distance" (S/D) between adjacent excavations everywhere should be greater than 4, giving an extraction ratio of 25 percent or less.

Using the SANCHO finite-element large-strain creep code, Sandia has done a structural analysis of the Title I design and compared this with two alternative layouts of the repository excavations (Krieg et al. 1979). In this analysis, a "standard structural model" for the geology was based on data from the ERDA 9 borehole (Wawersik 1979); mechanical properties for the salt were taken from SAND79-1853 (Munson and Dawson 1979); and, for other rocks and seams, properties were taken from the literature or estimated. The two alternative layouts both comprised uniformly spaced rooms: one layout with rooms 33 ft (10 m) wide separated by pillars on centers of 127 ft (38.6 m), giving the same overall extraction ratio as that in the Title I design; and the other with rooms 50 ft (15.2 m) wide separated by pillars on centers of 236 ft (71.7 m), giving a slightly smaller extraction ratio.

Even though the analysis was made for periods up to only 10 years, the two alternative layouts were shown to be superior to the Title I design, which showed horizontal convergence of the excavations as much as 4 times greater than that for a single-drift configuration. In the far field, a stress disturbance was found to extend over the entire horizontal span of the pillars, tending to confirm the criterion that the local extraction ratio should not exceed 25 percent.

An analysis such as this, based on limited data, uses many assumptions and may contain important omissions. In view of the pervasive changes in stress that occur within 10 years and of stress concentrations at stratigraphic discontinuities, it should be noted that Serata chose pillars 360 ft (109 m) wide to achieve isolation between sets of adjacent rooms. In any event, the incorporation of a limited number of major barrier pillars several hundred feet in width, as proposed in the modular design, would make it unnecessary to rely on pillars 100 ft (30.4 m) wide acting infallibly as "infinite pillars." Although, as stated above, the local extraction ratio within each module could safely be as high as 25 percent, the overall extraction ratio for the repository, including these barriers, should be significantly lower.

The analysis shows far-field effects brought about by relatively small amounts of convergence across the excavations in the short term (10 years). Waste and backfill in these excavations are likely to have a void space of about 40 percent, unless special procedures are developed for greater compaction. In the longer term, partial compression of this void space will occur as a result of much greater convergence across these excavations than that calculated in the analysis. Correspondingly greater far-field effects, particularly at stratigraphic discontinuities, may disrupt the salt in a very different way than would geologic events in the absence of man-made perturbations. Assumptions based on the behavior of salt in its pristine conditions may not be valid. Accordingly, analyses of this kind should be done for much longer periods of time--say 50, 100, and 1,000 years. Such analyses should address the question whether, if the intrinsic self-healing, viscous properties of the salt are to be used to ensure isolation, closure of the excavations will need to be limited to values much lower than those that would prevail if the cavities were filled with waste and backfill having an initial total void space of about 40 percent. A finding that closure should be limited would have important implications for waste forms and backfills.

Closure of the excavations, even in the long term--say between 100 and 1,000 years--is not likely to reduce the void space in the waste and backfill to a negligible value. A void space of the order of 10 percent is a likely equilibrium condition, and such a void space will result in a hydraulic permeability significantly greater than that of the pristine salt. Thus the excavations of a repository make up a network of interconnected hydraulic conduits in the salt mass. Although stratigraphic discontinuities, breccia pipes, and brine reservoirs are known to occur in salt, geological evidence indicates that the self-healing properties of the salt in its undisturbed condition make these relatively unimportant in connection with the dissolution of salt beds. However, the perturbation of these geologic features by the repository excavations and the establishment within the salt of an extensive interconnected network of hydraulic conduits may change the effects of these geological features and render the salt much less stable than has been assumed.

A careful analysis of such effects should be made, though they would not be expected to be greater than those resulting from scenarios of water flow between two aquifers (Bingham and Barr 1979). There has recently been discussion of increasing the extraction ratio to accelerate closure of the excavations and, perhaps, create additional space for the disposal of waste. Very careful consideration must be given to such proposals. At some point, the degree to which the salt is perturbed by the excavations will affect adversely the safety of the repository and the ability of the salt to isolate the waste from the biosphere.

The implication of the proposals to accelerate closure--that excavations should not be left standing with significant void space--is probably correct and is, in fact, another aspect of the concerns discussed above. An adequate study of these problems should be made to determine whether it is necessary to seal the excavations in such a way that their void space and permeability are very much less than is currently envisaged. Such a study is needed to show that the intrinsic properties of salt can be taken advantage of to effect safe isolation of radioactive waste by deep geologic disposal.

CHAPTER 4

ACCEPTANCE CRITERIA FOR TRANSURANIC WASTE

A table of acceptance criteria for transuranic (TRU) waste, from the WIPP DEIS (U.S. DOE 1979), is reproduced here as Table 4.1. These criteria are principally concerned with factors that affect the short-term operational aspect of WIPP, that is, the emplacement and 10-year retrievability of containers of waste. The only long-term concern that is covered by a criterion is that of gas generation. Environmental impacts of transportation of waste packages to WIPP are not considered to be part of the waste acceptance criteria. These impacts are treated in Section 3.2.3 of the DEIS.

The most debatable of the acceptance criteria for TRU waste is the inclusion of organic materials such as wood, paper, plastics, and fabrics. The presence of these materials raises questions about fire in the short term and about gas generation and formation of organic complexes with radioactive materials in the long term.

FIRE

The criteria in the DEIS place no limit on combustibles, as long as they are enclosed in steel drums or in wooden containers with steel overpacks. This decision is supported by analysis of various accident scenarios, and the consequences of the accidents are estimated from fire tests documented in Section 4 of Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP (Sandia 1979).

The relevance of these tests is open to question, because all were made in the open rather than in the confined spaces where operations will actually be carried out; that is, within the surface processing buildings and underground. In a sense this is a conservative evaluation, because a fire in a confined space tends to extinguish itself as the available oxygen is depleted. However, there are important factors operating in the other direction. Firefighters are quickly incapacitated or panicked by accumulation of smoke and heat, failure of lighting, and depletion of oxygen. Furthermore, the forced-draft ventilation system that must be used in underground workings may have the effect of propagating and intensifying the fire.

TABLE 4.1. Interim Waste Acceptance Criteria for Contact-Handled TRU and Remotely Handled TRU Waste

Criterion	Contact-handled TRU waste	Remotely handled TRU waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpack	No criterion; quantities are insignificant, and processing will probably not be available
Gas Generation	Gas-generating materials in any single storage room may not exceed 10% by weight	No criterion for above reasons
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix; double containment allowed for special cases; sludges must contain no free liquid	Same as for CH TRU waste
Explosives	Not allowed	Same as for CH TRU waste
Pyrophorics	Small quantities of radionuclide-metal pyrophorics may be accepted with other waste forms	Same as for CH TRU waste
Hazardous materials	Allowed only with special procedures and precautions	Same as for CH TRU waste
	CONTAINER	
Design Life	10 years to allow retrievability	Same as for CH TRU waste
Structure	Type A requirements	Same as for CH TRU waste
	PACKAGE	
Structure	Type A; any damaged container must be overpacked	Same as for CH TRU waste
Handling	Devices to allow handling by means of a forklift	Axial lifting pintle
Weight	Less than 12,000 pounds	Less than 10,000 pounds
Dimensions	Not larger than 8 by 12 by 9 feet	24-inch diameter, 15-foot length
Radiation		
Surface-dose rate	Not exceeding 200 mrem/hr; sources producing more than 5000 ft^3/yr must produce waste with a 3-month average of less than 10 mrem/hr	Less than 100 rem/hr
Surface contamination	49 CFR 173.398	49 CFR 73.398
Criticality	49 CFR 173, Subpart H	30-gallon drum, 100 grams fissile; 55-gallon drum, 200 grams fissile; DOT-7A, 500 grams fissile
Thermal power	Color code if greater than 0.1 W/ft^3	No criterion

SOURCE: U.S. Department of Energy (1979).

Fires underground are well known from mining experience. They are particularly difficult to control. To extinguish such a fire it is generally necessary to cut off the supply of air. In principle this can be achieved by interrupting the ventilation air, or by supplanting the air by steam or some other noncombustible gas. In practice, it has proved to be very difficult to cut off completely the flow of air to underground fires. Even a low rate of combustion can generate high temperatures, because underground combustion sites are well insulated thermally. If the fire is successfully extinguished by ventilation control, the burned area may take a long time, even months, to cool off by conduction. Readmission of air before temperatures have dropped below the ignition point merely restarts the fire.

Fire control should be easier in a salt repository than in a mine. It is probable that a dependable fire-extinguishing system can be designed, using some combination of dry powder, foam (to control burning diesel fuel), and fog (to cool the burning material and displace air). For fire safety to be fully credible, however, a waste disposal configuration should be stipulated that will self-extinguish without any fire control measures whatever. Such a configuration involves both waste acceptance criteria and repository design.

To provide a self-extinguishing configuration it is not necessary to be concerned about the manner in which the fire starts, other than to assume that the initial energy is a pulse of finite magnitude and duration. It is further assumed that the mixture of combustible and noncombustible materials is arranged in a tunnel-like configuration, supplied with a continuous and unidirectional flow of ventilation air at ambient temperature, which carries the combustion products and the associated heat of combustion over and through the unburned material. Whether or not the fire propagates under these conditions depends on the heat balance; that is, on whether the heat liberated by reaction of oxygen with a combustible component of the tunnel contents is sufficient to raise the temperature of neighboring components to the ignition point. This heat balance should be calculated for various ratios of combustibles (boxes, plastics, etc.) to noncombustibles (steel containers, concrete, backfill salt, and the nitrogen of the ventilation air).

A meaningful fire test could be carried out in a tunnel packed with simulated TRU waste packages in a proposed repository configuration, with or without salt backfill, supplied with forced ventilation. The fire could be started with diesel oil or any other source of an intense heat pulse.

GAS GENERATION

Gas generation by TRU waste and the possible pressurization of the repository are considered briefly in the WIPP DEIS (pages 9-133 to 9-136) and exhaustively in several Sandia reports (Molecke 1979a,b; Sandia 1979). These documents conclude that bacterial action is the dominant potential source of gas production, with gas production from the plywood boxes covered with fiberglass-reinforced polyester (FRP) being the largest single contributor in this category. This conclusion is independent of whether aerobic or anaerobic environmental conditions are assumed.

The analysis of gas generation sources has been carried out by resolving every doubt in the direction of higher gas generation potential. In an apparent effort to get measurable gas evolution in a reasonable time, the experimenters added water and nutrient salts to comminuted organic waste and then used the results of these accelerated tests to estimate possible gas evolution rates. It is not clear from the text whether any determination was made of the magnitude of the acceleration factor implicit in the tests. Such a factor might have been estimated by carrying out the tests at a series of controlled relative humidity levels that could be extrapolated to the level expected in the sealed repository.

Humidity obviously has important relevance to both bacterial action and corrosion, and efforts should be made to measure or estimate it reliably. It would not be surprising to find that the true gas generation rate is quite low, owing to the desiccant effect of the large mass of salt surrounding a sealed repository. The metabolic activity of protoplasm effectively ceases if the material is dried to the point of rigidity. Many organisms can survive for an extended period in a dry environment, but they do not interact with the environment under these conditions. The recovery of wood, cloth, and mummified animal remains from Egyptian tombs after more than 3,000 years is a well-documented example of the preservative effect of moderately low humidity. The contents of steel drums will be exposed to this desiccation, because the plastic gaskets used to seal the lids are relatively permeable to water vapor. It is reasonable to assume that during a storage period of hundreds of years the contents of the drums will reach a humidity level dictated by the ambient salt.

A neglected element in the evaluation of the potential for repository pressurization by biologically generated gas is the fact that metabolic activity is usually poisoned by the accumulation of metabolic products. On this score alone it is doubtful that methane or carbon dioxide pressures of hundreds of atmospheres could be produced through biological activity. Published literature in this area should provide sufficient information to place a reasonable upper limit on this type of pressurization.

The other major potential gas source is the steel drums themselves. A chemical reaction can be hypothesized that would generate large quantities of hydrogen by reaction of metallic iron with the water contained as brine in the surrounding salt. The DEIS concludes that this reaction will not occur to a significant extent in the initially aerobic environment of the drums. This conclusion is correct, because gaseous oxygen will depolarize the cathodic portions of the metal surface before the potential reaches a level sufficient to generate gaseous hydrogen from water. There is, however, a great deal of steel and a limited supply of air after the repository is sealed, so there is a distinct possibility that the repository will reach an anaerobic state. In this condition, and assuming an adequate supply of water (brine inundation), the DEIS predicts that hydrogen will be generated at the rate of 0.5 mole/m^2 year.

This rate would appear to be an overestimate. It is known from practical experience that, at ordinary temperatures, iron does not decompose water to liberate hydrogen unless the pH reaches 3 to 4. The pH of the Salado brines is not reported in the documentation. It seems unlikely to be so low, unless sour gases (CO_2, H_2S) are present at high partial pressures.

Radiolysis was also discussed as a source of gas generation. In view of the low level of total radioactivity in TRU waste, however, the rate of radiolytic gas generation estimated in the DEIS is negligibly small--only a fraction of that assumed for microbial action.

The computational model used to calculate the repository pressurization associated with gas generation is straightforward. The conclusion that the repository pressure will be below the lithostatic pressure even for the bounding 0.5 microdarcy case is acceptable, especially in view of the fact that the source term used for the gas generation rate is probably too high by orders of magnitude, as just discussed.

In view of the minor importance of gas generation for projected TRU waste, it is suggested that consideration be given to dropping the waste acceptance criterion relating to gas generation, while restricting the disposition of organic materials in accordance with the self-extinguishment criterion stated above.

COMPLEXATION

So many variables are involved in the quantitative evaluation of the effect of complexation on the transport of dissolved radwaste elements in an aquifer that writers of the DEIS have calculated transport rates both with and without allowance of credit for adsorptive retardation. Neglecting retardation is equivalent to assuming that all dissolved ions are fully complexed, which is highly unlikely.

IMMOBILIZATION

This criterion specifies that waste sludges must contain no free liquid, such as drained or exuded water. It is necessary to specify somewhere how the presence of free liquid is to be detected if this criterion is retained.

The criterion implies that sludges not associated with free liquid are acceptable. This contradicts the recommendation in supporting document SAND79-1305 (Sandia 1979) that sludges should not be accepted. Perhaps the question of the acceptability of sludges could be resolved by a measurement or calculation of the quantity of moisture that can be absorbed by a quantity of crushed Salado salt.

PACKAGE STRUCTURE

It would be well to be specific about the disposition of any drums that give evidence of being internally pressurized (bulging head or bottom). Limited field test data (Sandia 1979) suggest that only small overpressures (4 psi) will be encountered, but it is necessary to be alert, in view of the field observations that flammable and explosive gases can occur within these drums.

The amount of void space present within the waste packages is probably significant, particularly in packages filled with clothing, wipes, and the like. This volume should be estimated and added to the void volume associated with the backfilling operation, because the packages will surely be crushed during the planned convergence of the repository walls.

SOLUTION RATES

Solution rates become a significant consideration in the long-term release scenarios discussed in SAND78-1730 (Bingham and Barr 1979) in which the repository is flooded. Questions of solution rates and mechanisms were finessed in these scenarios by making the estimate that the wastes dissolve as though they were salt.

It is desirable to consider separately each radioisotope-bearing material in TRU waste and make some sort of conservative but realistic estimate of its solution rate. The materials in question are identified in several sources as plutonium oxide, plutonium metal, "first-stage sludge," sludge concrete, and pyrolysis slag (in case pyrolysis is carried out).

The solution rate of pyrolysis slag, for example, might conservatively be taken as equal to the leach rate of one of the proposed waste disposal glasses in the bulk leach test, that is, about 10^{-6} g/cm^2 day, decreasing by a factor of 10 in one year and remaining constant thereafter. Pyrolysis slag will have a higher content of silica and alumina than borosilicate waste disposal glass, and these are the network-forming components that impart durability to glass.

Hydrothermal conditions need not be considered, because there is no significant generation of heat in transuranic wastes. The fact that the leachant is brine rather than pure water needs to be taken into consideration. Data on leach rates for glasses in brine are only now becoming available.

CHAPTER 5

ENVIRONMENTAL EFFECTS

This chapter is based on the Panel's review of the WIPP Draft Environmental Impact Statement (DEIS). One of the main purposes of that document is to estimate possible radiation exposure of both project employees and the general public. Such exposures could arise from transportation of the waste to the repository site, surface storage of waste at the WIPP site preparatory to emplacement, and accidents that may occur during normal operation of the facility. In addition, radioactive waste will be generated in the course of operating the repository, and all of these may result in exposures to persons both on-site and off-site. Finally, there may be releases of radioactive material to the environment if the repository is breached sometime in the future. These potential sources of exposure have been examined in the DEIS and are discussed here.

TRANSPORTATION TO THE REPOSITORY

Transportation of radioactive materials has been regulated for years by the Department of Transportation, the U.S. Postal Service, and, in the case of intrastate shipments, by the U.S. Nuclear Regulatory Commission and the states. Regulations have been promulgated that prescribe the methods of packaging, the maximum quantity of radioactive materials that can be included in any one package, and the maximum number of packages that can be included in any one shipment. Hundreds of thousands of shipments have been made over a period of more than three decades, and although many vehicles carrying radioactive waste have been involved in accidents, the procedures have thus far been successful in safeguarding the public. It should, of course, be emphasized that most of the shipments involve very small quantities of radioactivity.

Quantitative estimates of the doses to be expected to crews involved in the shipments, to passing motorists, and to inhabitants along the shipping route have been made by means of RADTRAN, a computer code approved by the U.S. Nuclear Regulatory Commission for making estimates of occupational and public exposure from shipments en route. The dose estimates are of the order of one thousandth of the dose normally received from natural radioactivity (U.S. DOE 1979, pages 6-15 to 6-19).

Of greater concern are the doses that might result from transportation accidents. DOT Type B containers are assumed to be used in all shipments of high-level waste and spent fuel. The standard test sequence required by DOT and NRC for Type B containers involves the following:

a) A 30-ft drop onto an unyielding target
b) A 40-in. drop onto a 6-in. diameter probe
c) A 30-min fire at 1475°F (802°C)
d) An 8-h submersion in water

From statistical studies reported in the literature, the DEIS concludes that more than 99.5 percent of all accidents will be less severe than the test conditions required by the regulatory standards. The DEIS then proceeds to analyze the consequences of accidents more severe than those covered by the regulations.

Four such scenarios are presented: a rail accident involving contact-handled TRU waste, a truck accident involving contact-handled TRU waste, a rail accident involving remotely handled TRU waste, and a rail accident involving spent fuel.

The dose calculations associated with the four scenarios are typically conservative (i.e., they estimate the worst-case dose), in that the meteorological conditions that lead to the highest population doses were chosen and the accidents were assumed to occur in urban areas.

Inhalation was chosen as the principal pathway to humans, and the doses were calculated by using the computer code AIRDOS II. For the meteorological conditions assumed, the maximally exposed individual would be about 0.5 mi (0.8 km) from the accident and would receive a whole-body dose of about 1 rem. If the accident occurred in a small urban area, about 6,000 people would be exposed, for a total dose of about 4,000 person-rems. (A person-rem is the unit of population exposure obtained by summing individual dose-equivalent values for all people in the population. Thus, the number of person-rems contributed by 1 person exposed to 100 rems is equal to that contributed by 100,000 people each exposed to 1 mrem (National Research Council 1980).) A spent fuel accident in a large urban area would expose about 106,000 people, who would receive a whole-body dose of 8,300 person-rems and a bone dose of 9,400 person-rems. The dose commitment to the lung would be somewhat less, about 2,300 person-rems. On the basis of the projected number of shipments, actuarial records on the type and frequency of transportation accidents, and the known distribution of the various environmental parameters, the annual frequencies of the accidents described in the four scenarios are estimated to have upper limits ranging from 1.9×10^{-6} to 8.6×10^{-5} (1.9 to 86 chances in a millon of occurring each year).

Under the most pessimistic of the assumptions adopted in the DEIS for transportation accidents, the dose to the maximally exposed individual would be within the legally permissible dose limits applied to certain types of accidents involving nuclear facilities. The population dose exposure in person-rems suggests that, in the most pessimistic scenario, the exposures would result in a maximum of about one additional cancer during the lifetime of the exposed population.

Intentional destructive acts are considered briefly in the DEIS. The Panel accepts the conclusion that such acts are not likely to produce consequences more significant than those resulting from the other accident scenarios described.

SURFACE AND UNDERGROUND RELEASES DURING NORMAL OPERATION

Waste delivered by either rail or truck to the WIPP site will be unloaded and passed through airlocks to the waste-handling building. The handling procedures are described in detail, and a number of unlikely assumptions are made as to the levels of contamination. For example, it is assumed that all waste packages are contaminated to the maximum level of surface contamination permitted by U.S. NRC/DOT regulations. The total radioactivity that would be released to the environment from both surface and underground operations is estimated to be 8.3 Ci/year, of which 94 percent would be ^{85}Kr. Throughout the analysis, the assumptions are conservative, so the final dose estimates are exaggerated.

The requirements of the DEIS for radiological impact analysis during normal operations could probably be met by simply noting that many years of experience with the handling of properly packaged waste provide assurance that the dose to the employees can be kept well within prescribed limits and that the dose off-site would be so low as to be undetectable.

The occupational doses to forklift operators at WIPP from handling the contact waste are estimated to range from 15 to 1,900 mrems (0.015 to 1.9 rems) per year. The occupational doses from remotely handled waste have not yet been evaluated. The estimated doses, though within acceptable limits, are too high for routine operations, since other exposures from nonroutine events may occur.

The results of rather straightforward dose calculations, based on a conservative set of assumptions, show that for an individual at the closest point of habitation, the maximum dose (to the bone) is 0.003 percent of that received from natural radioactivity, and the whole-body dose would be less than 0.0001 percent of background (U.S. DOE 1979, page 3-10).

ACCIDENTAL RELEASES DURING OPERATION OF THE FACILITY

Accidents that may occur in the course of handling the radioactive waste will have a potential for exposure to both employees and nearby inhabitants. The consequences of a waste-handling accident are examined by analysis of 43 scenarios ranging from a vehicle collision in the receiving area (no radioactive material released) to various failures of the drums and canisters from collisions, drops down mine shafts, spontaneous combustion, and external fires. The radiation doses are calculated from estimates of the quantities of radioactivity released, the atmospheric concentration at a given location per unit of radioactivity released based on meteorological observations at the site, and measured population distributions.

The worst case for contact-handled TRU waste involves an underground fire, in which case the 50-year bone dose commitment off-site is estimated to be about 0.01 microrem. For remotely handled waste, the worst case would be an accident in which a spent fuel cask is dropped down the waste shaft, in which case the maximum dose to a nearby inhabitant would be 10 microrems to the lung. The "population doses" have also been calculated for the worst sector, inhabited by 28,700 people; it is estimated that they would be less than one-millionth the dose received from natural radiation.

LONG-TERM EFFECTS: RELEASE OF RADIONUCLIDES AFTER CLOSURE OF THE REPOSITORY

To assess the long-term performance of the proposed WIPP repository in terms of possible and potential releases of radionuclides, several release modes are analyzed in the WIPP DEIS. The most serious of the cases considered is development of a postulated fault that diverts water from the Rustler formation above the repository such that water flows down into the repository and dissolves the salt and radioactive waste. The resulting saturated brine solution then flows back up to the Rustler formation and eventually out to the Pecos River at Malaga Bend. It is assumed that the diversion of the water from the Rustler aquifer into the repository can occur at any time after the closure of the repository and that some hypothetical individual relies on the Pecos River water as his only source of potable water. The dose to that individual is then calculated. The available data indicated that the presently understood hydrology of the proposed WIPP site does not lead to any expectation that water from an upper or lower aquifer could or would be so diverted as to flow into the repository.

Inadvertent drilling could also establish a hydraulic connection between the Rustler formation and the repository. Bingham and Barr (1979) estimate the probabilities of breaching the repository salt formation by inadvertent drilling to be 0.1 at 1,000 years, decreasing to 0.001 at 10,000 years and later, as the importance of hydrocarbons in the economy decreases. The Sandia analysis assumes that once water intrudes into the repository it will eventually contact the waste. The repository is assumed to contain TRU waste, as specified earlier in this report, and an array of 6,000 spent fuel elements, each in a stainless steel canister.

The water entering the repository is assumed to dissolve the salt until it reaches the concentration of saturated brine. When the dissolution front intersects a package of TRU waste or a canister of spent fuel, the waste material is assumed to dissolve at the same rate as the surrounding salt; the much lower solubility of the waste material and the relative insolubility of some of the contained radionuclides are disregarded. But even this extremely unrealistic assumption yields such small dose estimates that more detailed calculations taking into account the actual dissolution rates of the waste material are not made in the DEIS. However, the use of such a simplistic model of the waste material will lead many readers into believing incorrectly that little additional protection is offered by the long-term stability and corrosion resistance of the waste material.

The release model assumes that the saturated brine solution, with its dissolved radionuclides, flows back up to the Rustler aquifer. Various possible mechanisms for the upward flow have been considered in the Sandia analysis (Bingham and Barr 1979). For example, degradation of the waste by the intruded water might generate gas, with an accompanying pressure rise. If accompanied by sequential breaching, closure, and rebreaching, a pressure gradient forcing upward flow could occur. A more plausible mechanism, not considered by Sandia, would be the venting of pressurized brine during operation of the repository or after its closure. It is also possible that this driving force could be caused by a rise in fluid potential within the Bell Canyon aquifer in the event of a return to pluvial conditions. These possibilities require further consideration, though they have been bounded by existing scenarios.

Sandia also considers the possible creation of upflow by thermal convection, resulting from heating of the brine solution by spent fuel, which is the only heat-generating waste considered in the DEIS. If this were to occur, it would be limited to the heat-generating period of about 1,000 years. But the number of spent fuel elements considered in this analysis is in fact too small to set up sufficient thermal convection for the creation of an upflow from the repository. The properties of the waste material and the placement geometry preclude the possibility of nuclear criticality, with its accompanying heat generation. It can only be concluded that a plausible mechanism by which the saturated brine could flow back up to the Rustler aquifer has not been identified in the DEIS.

Having assumed that a contaminated and saturated brine solution does reenter the upper Rustler aquifer, Sandia then calculates the hydrological transport of this contaminated brine through the aquifer to the Pecos River, over an assumed distance of 21 km--the shortest or straight-line distance from the repository to the Pecos. Transport is assumed to occur largely through the dolomitic rock. Further, the assumed range of hydraulic gradients and permeabilities used in their analysis result in velocities of water transport varying from 0.23 to 4.6 m/year and water transport time varying from 5,000 to 100,000 years. These estimates appear to have been suitably conservative for the Rustler hydrology because the pathway for groundwater flow is expected to be twice as long as the straight-line distance used in the calculations. The transport distance has been estimated with the use of more recent and more abundant water level data obtained from drillholes completed in the Rustler aquifer.

Still not adequately addressed, however, is the possible presence of zones of fracture concentration that may be revealed by fracture traces and lineaments that may provide distinct, more conductive channels for water flow than considered in the Sandia analysis. Such privileged pathways, if present, could cause groundwater to flow along still undefined pathways with orientations different from those assumed, and at greater velocities. The maximum volumes are limited by the observed flows into the Pecos River along the Salado-Rustler contact zone (U.S. DOE 1979, page 7-69). The presence of privileged pathways need not be defined by flow lines drawn at right angles to equipotential lines using the most up-to-date Rustler water level data or by test holes located with other site selection criteria in mind. Their presence and potential significance to water flow can be determined by mapping fracture traces and lineaments, matching permeability data obtained from existing test holes with locations of existing test holes and lineaments, and from controlled drilling and field testing of one or more lineament-related structures if none have been penetrated to date. Shorter, more abundant rock fractures and joints are harder to map lacking adequate outcrops but are more apt to be penetrated by existing drillholes and be reflected in field-derived permeability data.

Using the present analyses, the dissolution and transport processes take over 5,000 years for even the nonsorbing radionuclides and far longer for the sorbing species. Even if fission products are included among the wastes, this gives ample time for ^{90}Sr and ^{137}Cs to decay without the additional delaying effect of sorption. Sorption by the dolomite precludes the release of the transuranics, although some of their more toxic decay daughters, such as ^{226}Ra, contribute to the later doses to man (U.S. DOE 1979, page K-20). Weakly sorbed fission-product radionuclides, such as ^{129}I and possibly ^{99}Tc, are also contributors.

The sorption data listed in the DEIS were derived from more than one source. It is not clear to what extent these data are applicable to the geochemistry of the Rustler formation and to sorption from solutions containing appreciable concentrations of dissolved salt. These uncertainties affect the estimated doses from ^{226}Ra but not the estimated doses from the weakly sorbing species, such as ^{129}I. No discussion of the effects of such sorption uncertainties has been found in the report.

The exact procedures by which the dose estimates have been made are not fully explained in the DEIS. The dose estimates were made by the U.S. Nuclear Regulatory Commission computer code LADTAP, but the required input data are not given. From consultation with the Sandia staff, however, it has been determined that the maximally exposed individual is one who is located at the Malaga Bend of the Pecos River, where he catches and eats 21 km of fish per year. He also consumes 730 liters per year of the highly saline, nonpotable water from the Pecos River at Malaga Bend, and he spends 82 hours per year in recreation on the river or its shoreline. His recreational use of the river contributes insignificantly to the dose received. Because exposure is thus from ingestion of food and water, the dose varies from organ to organ, depending on the metabolic characteristics of the individual nuclides.

The doses to the maximally exposed individual are estimated in the DEIS to be small, as can be seen from the following summary:

Organ	Annual Dose, mrem/year
Whole body	0.4
Thyroid	1.9
Bone	2.1
Kidney	0.41
Lower large intestine	0.16

(The dose from natural radioactivity is about 100 mrem/year in most localities (NCRP 1975, page 108).)

The scenario selected in the DEIS as the bounding case appears to be totally implausible. Apart from the implausible mechanisms for water intruding into the repository and returning to the aquifer, the assumptions in each step of the analysis tend to exaggerate the dose estimates. For example, the waste is assumed to dissolve as rapidly as salt; no solubility limits for the waste material and for its radionuclides are considered; upper values of the Rustler hydraulic permeability and transmissivity measured to date are assumed; the sorption coefficients may be lower than realistic; and the transport distance assumed for the analysis is less than the actual distance, though fracture flow is not considered. Finally, no allowance is made for the fact that the radionuclides emerge into the Pecos River, the water of which is already not potable because of high salinity. It is not consumed by man or beast, and the river does not support a significant population of fish or shellfish.

If this scenario is discarded, another becomes the bounding case. It is nearly as implausible and results in even lower doses. But it is not even clear that the scenarios described in the DEIS do include the bounding case. For example, however unlikely the probability that solution mining will be practiced at the WIPP site, the consequences of doing so might be far more severe than the scenarios considered in the DEIS.

Though fracture flows could yet be discovered, their total flow would be limited and would be mixed in the saline Pecos River. With this exception, by compounding implausibility on implausibility and conservatism on conservatism, the DEIS does indeed convey the message that the long-term risk to future populations from the hydrological transport of radionuclides from the WIPP repository is likely to be extremely small.

CHAPTER 6

IN-SITU TESTS AND EXPERIMENTS

Assuming the prior conduct of extensive laboratory and field investigations, calculations, and analyses, a sequence of confirmatory underground in-situ tests and experiments will be required when access to the proposed repository horizon has been provided by means of an exploratory shaft. First, geotechnical uncertainties in the characterization of the essentially unperturbed site will need to be resolved by direct observation. Second, if the site is not disqualified by the results of these observations, other in-situ tests and experiments will be needed to evaluate the physical characteristics of the host media that contribute to the achievement of acceptable isolation. Third, if the site still appears to be suitable, additional tests will be required to corroborate the design of the repository, demonstrate the viability and effectiveness of underground techniques such as backfilling, and obtain measurements of initial rock response to excavation and waste emplacement as part of the predictive modeling effort.

Such a neat sequence is unlikely to occur in practice. For instance, comprehensive plans have been made for in-situ experiments, aimed at the second and third of the purposes listed above, to be conducted in potash mines in southeastern New Mexico. Detailed plans should be developed and thoroughly reviewed prior to sinking an exploratory shaft for the purposes of in-situ investigations. To the extent possible, such plans should be developed well in advance, specifying the issues that need to be resolved, the criteria to be satisfied, the measurements to be made, the instrumentation required, and the proposed methods of interpreting the expected data. In-situ work will be the final step in the process of learning what is not known and confirming what is thought to be known, before commitment to actual repository construction and operation. This may require a degree of redundancy and the concurrent conduct of many different kinds of experiments. Consistency among several different measurements often proves to be an important basis for confidence in experimental findings.

It must be recognized that instruments capable of reliable operation underground for years—or even decades—may not exist. Difficulties have been experienced, for example, in making even simple temperature measurements for such periods. Major emphasis therefore must be placed on the development of suitable instrumentation.

It is very difficult to accelerate in-situ tests without raising serious doubts as to the validity and interpretation of their results. Accordingly, every advantage should be taken of opportunities to begin such tests early, to conduct them on a sufficiently large scale, and to continue them for as long as is practicable prior to the operational emplacement of radioactive waste.

The Panel is not in a position to draft a plan for such tests and experiments. But after several briefings and examination of reports on the subject, we take this opportunity to point out a few areas of concern and what appear to be some deficiencies in existing plans.

RESOLUTION OF GEOTECHNICAL UNCERTAINTIES

An exploratory shaft will provide an opportunity to verify the geologic and hydrologic data obtained from the eight deep holes already drilled on site. The Panel understands that, as of the end of 1979, plans call for the sinking of an exploratory shaft 12 ft (3.6 m) in diameter to the level of the proposed repository by downhole drilling, using reversed mud circulation. A tubular steel lining, extending about 820 ft (249 m) from the surface to the top of the Salado formation, will be grouted in place. The location of this exploratory shaft is presumably coincident with the proposed storage exhaust shaft, placing it some 500 ft (150 m) northwest of the ERDA 9 test drillhole. In this location, the shaft should pass through the Santa Rosa sandstone, the Dewey Lake Red Beds, and the Rustler formation, as well as more than 1,000 ft (300 m) of the Salado formation, in which it will be unlined.

The Santa Rosa sandstone is the principal aquifer in several areas (although not at the site or in areas to which the site would discharge); the Dewey Lake Red Beds contain no aquifers. The Rustler formation contains two water-bearing dolomite beds, and a third brine aquifer is located at the contact with the Salado. In view of this geologic sequence, through which every shaft of the proposed repository will have to pass, it seems unfortunate that the method of sinking the exploratory shaft precludes visual observations and, to a large extent, other testing of the sequence for which this shaft will provide the first opportunity. Careful consideration should be given to using some other method of sinking this shaft that would permit geologic mapping and hydrologic testing of the different rock layers.

The Salado formation itself is not simple: it contains interbedded salt, anhydrite layers, clay seams, and partings, all of which have been taken into account in specifying the depth of the proposed repository and in its underground design (Krieg et al. 1979). Moreover, there remains a possibility that breccia pipes, large brine pockets, or intrusive dikes may be encountered. Once the exploratory shaft has reached the proposed depth of the repository, parallel horizontal exploratory drifts consistent with the planned design should be driven out as far as safety permits, to obtain first-hand information concerning the structure, properties, and behavior of the salt at the horizon of the proposed repository excavations.

Furthermore, differences can be expected between the properties of laboratory test specimens from the Salado formation and properties of the formation en masse. In-situ measurements should reveal these differences and allow them to be taken into account in the design and predicted performance of the repository.

ISOLATION MECHANISMS AND FAILURE-MODE EXPERIMENTS

The specific characteristics--or even the feasibility--of certain in-situ tests will, of course, be determined by the nature of the waste eventually to be accommodated. For instance, meaningful in-situ experiments on brine migration or radiolysis would be difficult to design and perform--and probably unnecessary--in the temperature and radiation regimes that would prevail if only defense transuranic waste were emplaced in the repository.

Regardless of waste type, however, some important work could be undertaken as soon as an exploratory shaft has been sunk. Evaluation could be commenced with waste packages, including engineered barriers but not necessarily containing radioactive material. Drifts developed from the shaft could be instrumented for large-scale tests of hydrological effects such as mass transport and nuclide migration. Large-scale permeability of the salt might be determined by psychrometric measurements of air flowing into and out of a sealed section of tunnel.

If the emplacement of heat-producing waste is contemplated, early in-situ tests and experiments on the effects of temperature should be undertaken. Initially, it is probably prudent not to emplace radioactive waste for this purpose but to use electrical heaters to simulate the thermal effects of canisters of waste and yet obviate the hazard of having to retrieve radioactive materials. The results of such a simulation should remove many uncertainties and increase the level of confidence with which a decision can be made whether or not to emplace high-level waste or spent fuel rods in the repository. The effects of radiation and possible synergistic effects between radiation and temperature, of course, would have to be tested separately, but this could be done with less risk on a much smaller scale.

The proposed experimental high-level waste emplacement would constitute an in-situ investigation of major importance, but it should not be attempted until and unless the development of the site has gone well beyond the exploratory shaft phase. The underground design should have been validated by in-situ testing, and all the additional shafts and equipment necessary for safe, large-scale excavation and materials handling should be in place and proven by a period of successful operation.

The radioactive waste in these experiments (except for special tests) will be encased in metallic canisters with walls thick enough to ensure that corrosive action, if any, will be detected by routine monitoring and inspection long before any radioactive material is exposed. In many cases there will also be overpacks of absorbent substances, and the holes in the salt in which the canisters will be placed may be lined with steel. Corrosion of metals is therefore the main concern. Corrosive substances include oxygen from the surrounding air, salt, and possibly brine. The surface temperature of the waste canisters will be one of the experimental variables.

Corrosion of mild steel in a salt environment has been studied extensively. Dilute brines are very corrosive in the presence of air, especially when the surface is alternately exposed to liquid and gas. Concentrated brines are not intrinsically corrosive to steel, as attested by the long and successful use of carbon steel heat-exchange piping in ice-houses. Even aeration causes little corrosion because of the low solubility of oxygen in saturated brine. Accordingly, it appears that whether or not there is brine migration along the temperature gradient associated with a high-level waste canister, corrosion of steel hole liners should be minimal during in-situ experiments lasting a few decades at most. A paper (Pigford 1981) discussing brine migration is being prepared by one of the Panel members.

On the other hand, stainless steel canisters that have been filled with hot glass may fail rapidly in contact with brine by stress corrosion cracking, although this type of failure can be postponed indefinitely by the use of overpacks and hole liners. In the experimental program, some of the canisters should be deliberately exposed to conditions that are expected to cause this type of failure. Of course, provision must be made for detecting failure in situ and for retrieving cracked canisters.

Corrosion of ferrous alloys may be expected if the repository is designed with such a dense loading of heat-producing waste that the temperature rises high enough to liberate HCl from the hydrated $MgCl_2$ present in the brine. This process is fairly rapid at or above 200°C. The Panel would not recommend use of a loading density that would cause such high temperatures in a repository, unless for experimental purposes.

Mild steel will corrode rapidly in an acidic (pH $\leq$ 3 to 4) aqueous solution. No data have been found in the DEIS or supporting documents on the pH of the brines that may be encountered in the Salado formation. If this information is in fact unknown, an effort should be made to obtain it.

Corrosion or other failures of the liners should be monitored during the experimental program, when any failures will give valuable information without significant environmental consequences.

VALIDATION OF UNDERGROUND DESIGN

If the results of preliminary exploration by horizontal drilling and lateral drifts are encouraging, consideration probably will have to be given to a second shaft, for reasons of safety and more complete evaluation of the site. However, prior to making any decision about a second shaft, test areas adjacent to the first one but far enough from it to avoid adverse effects should be set aside for several important tests that will be needed to validate whatever underground design is eventually decided upon. One of those should be a section designed according to the same methods as those used for the repository excavation but with much higher local stresses, so that excessive closure or other difficulties, such as instability of pillars, are expected to occur. This section should be instrumented as early as is practicable with closure meters, extensometers, and inclusion stressmeters, so that the behavior of the salt can be measured and compared with the design predictions and laboratory measurements of the properties of salt. Another important test would be a fully instrumented replica of the proposed repository excavations to ensure, at least in the short term before commitment to excavation of the full repository, that they behave as predicted by design.

The exploratory shafts and tunnels will provide the first opportunity to develop and prove in place the techniques for shaft sealing that will be a critical consideration. This may involve developing sections of test shafts parallel to the exploratory shaft especially for this purpose. In any event, tests of proposed sealing methods should be commenced as soon as practicable.

An item of particular concern is the Title I design proposal to store the salt on the surface and wet it for dust suppression. Even in the absence of wetting, salt stored on the surface will absorb water, and since it is proposed also to use this salt for backfilling the repository, the addition of water in the vicinity of the waste by this process does not appear to be well advised. Moreover, the porosity and permeability of the backfilled salt will far exceed that of the undisturbed salt deposit; unless proper precautions are taken, the backfilled tunnels could provide a ready access route for any intrusive waters.

Numerous in-situ tests and experiments will no doubt be needed to develop, prove, and demonstrate safe repository and equipment operation under normal and accident conditions. Although such tests and experiments may not be regarded as fundamental to deciding whether or not a particular site is suitable for a waste repository, two factors must be borne in mind. First, many aspects of repository design and operation will be determined to a large extent by the geological conditions encountered at the site. Second, unless the necessary equipment can be developed and operated safely, even the best potential site cannot be used.

CHAPTER 7

NATURAL RESOURCES AT THE WIPP SITE

A variety of natural resources underlie the reference site currently being considered for WIPP. Included are caliche, gypsum, salt, sylvite, langbeinite, crude oil, natural gas, and distillate, but potash and hydrocarbons are generally considered to be the most significant resources. A deposit of the potash mineral langbeinite [$K_2Mg_2(SO_4)_3$] is located 1,500 to 1,700 ft (450 to 510 m) below the surface; oil and gas resources are inferred to be located 4,000 to 14,000 ft (1,200 to 4,200 m) below the surface. Langbeinite is an unusual form of naturally occurring potash, important for preparation of potassium fertilizers in which chloride ion is absent (since chloride ion is harmful to some plants). The Carlsbad Potash District is by far the largest potash-processing area in the United States.

The objectives of this chapter are twofold: to evaluate the adequacy of the technical data base used to depict natural resources at the WIPP site, and to assess the adequacy of programs intended to evaluate the extent and implications of the presence of natural resources as it affects the suitability of the site as a repository for radioactive waste. The two chief problems arising from the presence of natural resources at the site are (1) the threat to repository safety that past or future exploration for the resources might entail and (2) the long-term denial of natural resources.

THE LONG-TERM DENIAL OF RESOURCES

The review of the WIPP DEIS and associated data base indicates that the analyses to date for valuing denied resources are adequate in terms of current market prices, assuming updating to reflect recent economic changes. More problematic, however, is the economic value to be assigned to long-term denial of resources.

The DEIS does not assign an economic value to denied resources. Rather, it indicates the significance of resources (and reserves) by comparing those present at the reference site with available resources in the region, the United States, and the world (see Table 7.1). For more detailed economic valuation of resources, it is necessary to consult the back-up studies. The value of denied resources in these studies is invariably calculated at present prices, with escalators

TABLE 7.1. Significance of the Resources and Reserves at the Reference Site

Deposit	Reference Site	Region	United States	World
		RESOURCES[a]		
Sylvite				
Quantity, million tons K_2O	10.44	500	1,000	100,000
Percentage at reference site		2.1	1.0	0.0104
Langbeinite				
Quantity, million tons K_2O	16.15	No estimate available		
Crude Oil				
Quantity, million barrles	37.50	1,915	200,000	Not Available
Percentage at reference site		2.0	0.019	
Natural Gas				
Quantity, billion cubic feet	490	25,013	855,000	Not Available
Percentage at reference site		2.0	0.057	
Distillate				
Quantity, million barrels	5.72	293	Not Available	
Percentage at reference site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	3.66	106	206	11,206
Percentage at reference site		3.4	1.8	0.033
Langbeinite				
Quantity, million tons K_2O	4.41	38[d]	38[d]	Not Available
Percentage at reference site		11.6	11.6	
Crude Oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at reference site		0	0	0
Natural Gas				
Quantity, billion cubic feet	36.85	3,865	208,800	2,520,000
Percentage at reference site		0.95	0.018	0.0015
Distillate				
Quantity, million barrels	0.55	169.1	35,500	Not Available
Percentage at reference site		0.32	0.0014	

[a]Data Sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.

[b]Data Sources: Hydrocarbons, Keesey (1976) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM, 1977).

[c]The U.S. Bureau of Mines (USBM, 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.

[d]Not an official estimate by the U.S. Geological Survey; see Section 9.1.4.

SOURCE: U.S. Department of Energy (1979).

built in for projected price increases. It is apparent that, with rapidly escalating prices, the value of hydrocarbon resources has been greatly underestimated. The estimate therefore needs to be updated.

In the case of potash, current prices were used to derive the estimate of potash products that could be produced economically. However, prices in the potash industry have been notoriously unstable over time (Bingham and Barr 1979), a factor that makes any long-term projections of resource value extremely difficult.

The valuations of natural resource denial may be quite sensitive to the economic assumptions underlying the projections. To cite several examples from the Bureau of Mines potash valuation (U.S. BOM 1977):

- "there will be a 2.9 percent annual growth in U.S. consumption of fertilizer (compared with a recent growth rate of 6.3 percent)." [page 33]
- "U.S. potash consumption will double by the year 2000, but domestic production will supply less than 10 percent of the total." [page 35]
- "there will be increasing physical limitations on potash consumption due to such things as the decline of available land for farming, more efficient use of fertilizer, new technology in the use of fertilizer, and a possible decline in the foreign market for U.S. food products." [page 33]

The data base at present contains only limited information on the size of potash reserves available elsewhere in the world. The substitutability of other sources (e.g., brines at Searles Lake, California, and Great Salt Lake, Utah; and synthetic langbeinite produced by solar evaporation of seawater) and their economic feasibility receive only passing mention in the DEIS and merit greater attention.

On the whole, the resource analysis, with the caveats noted above, appears to provide adequate baseline information. The commitment of the site for a waste repository would involve denial of natural resources, but such denial would probably have only a marginal impact on mineral resources at the national and even regional level, particularly if controlled drilling and mining are allowed within the outermost zone of the repository site.

Further research on the opportunity costs involved in natural resource denial is currently under way at the University of New Mexico.

NATURAL RESOURCES AND REPOSITORY SAFETY

Of considerably greater concern, however, are the implications of the presence of significant natural resources at a repository site for the long-term integrity of the repository. Numerous shallow holes have been drilled to evaluate potash resources, and some deep holes have been drilled for hydrocarbon assessments. Possible breach of the repository as a result of resource exploration at some future date, after records of its siting and purpose may have been lost, is a troublesome issue.

A wide variety of sources, including the National Research Council (1978), have formulated site suitability criteria (see Goad 1979) addressing the natural resources issue, and recent critics have directed attention to the risk implications of such resources at the WIPP site (R.W. Foster, memorandum to the WIPP Review Committee, n.d.; Sierra Club 1979). In a letter to DOE dated December 21, 1978, on the suitability of the Los Medanos study area as a repository site, Sandia itself notes that the natural resources site selection criterion is "not well satisfied by the WIPP site" and that "these concentrations of minerals may prove an enticement for future exploration and exploitation."

The chief risk studies that bear upon this issue are the analyses of 19 scenarios presented in Bingham and Barr (1979) and the 94 scenarios covered in the WIPP DEIS. Of the 19 Bingham and Barr scenarios, 5 include drilling for resources as a risk element. The study finds that 10,000 years from now drilling is still one of the most probable scenarios, but the consequences to the general public associated with nearly all these scenarios are estimated to be quite small. None of the included scenarios treats the purposeful mining of the radioactive materials themselves, although this has been cited previously as an intrusion factor.

The scenarios developed in the DEIS are consistent with Bingham and Barr's findings. The worst-case analysis for high-level waste involves the accidental transfer of radioactive materials to the surface of the earth, resulting from drilling activities involved in the search for natural resources 100 or 1,000 years from now. The maximum individual dose in that case is calculated to be 90 rems to the whole body. Such a dose, while exceeding the maximum permissible occupational exposure for one year, results in a risk that is small compared to that from nonradiological industrial hazards.

This scenario, however, may fail to bound the maximum credible event arising from natural resources conflict. Either solution mining for table salt 100 years after closure of a high-level waste repository or mining of radioactive materials themselves, whether purposeful or not, could produce consequences greater than those indicated in the worst-case analysis containing currently accepted bounding conditions. A recent study (Harwell 1979) argued both a high probability of human intrusion at salt domes and unacceptably large possible consequences. The significance of this assessment for the WIPP site should be carefully evaluated.

A major additional issue is the possible storage of spent fuel elements in the repository. Such waste is in fact a resource that increases in value over time. There is a strong possibility that sooner or later someone will seek to recover the material, whether or not there is still a historical record of it.

Bingham and Barr (1979) assign probabilities for intrusion in only a highly speculative and subjective manner. As a result, the ranking of scenarios by likelihood is open to legitimate debate. Given the residual uncertainties associated with the intrinsic inability to define probabilities of future human intrusion except in a gross and subjective way, and possible substantial consequences, the concern over resource conflict at the WIPP site appears merited.

The possibility of breach of the repository during exploration for potash and hydrocarbon after records of its location and contents have been lost must therefore be taken into account. It should be pointed out, however, that a repository for spent fuel or reprocessed high-level waste, even in a region free from mineral resources, may give rise to a geophysical anomaly that provides an incentive to explore it by drilling anyway.

No studies have been found that deal with the possible impacts upon long-term repository safety of exploitation of natural resources other than minerals (e.g., solar energy and its future effects upon population densities or undiscovered water resources). In its Geological Criteria for Repositories for High-Level Radioactive Wastes (National Research Council 1978), the Committee on Radioactive Waste Management of the National Research Council adopted, among others, the criterion, "No area with a present or past record of resource extraction, other than for bulk material won by surface quarrying, should be considered as a geological site for radioactive wastes" (page 13). That report also calls specific attention to the hazard posed by the spent fuel elements themselves if they are disposed of in a nonretrievable manner. While the Committee criteria are not intended as absolute or even of equal importance, they are intended "as a basis for the determination of the suitability of the repository site" (page 1). It is reasonable to infer that the burden of proof for long-term safety is on the developer if a criterion is to be overridden.

REDUCING THE RESOURCES CONFLICT

Given the difficulties posed for the long-term integrity of the site by the presence of natural resources, particularly langbeinite and hydrocarbons, and the value of the resources that must be foregone, the possibility of extracting these resources prior to, during, or after repository operation needs to be explored. It may be possible, for example, to hold the upper zones of potash as a reserve and mine them after the site is decommissioned or some time after sealing, if this can be done without compromising the integrity of the repository. The same tactic could be used for oil and natural gas--employing directional drilling--*if* the exploratory group can prove the existence of a probable trap that can contain hydrocarbons.

The safety issues involved in such a venture need to be carefully assessed. For example, is there any possibility that the extraction of hydrocarbons from underneath the repository horizon will facilitate the entrance of radioactive materials into an aquifer? Would the mining of the potash from above the repository possibly weaken the repository roof, or could it act as a depot for collecting a head of water that at some time could enter the repository? It needs to be pointed out, moreover, that extraction of the resources would not in any case resolve the future intrusion threat, for it is the perception of likely resources that will motivate future resource seekers. The *proximity* of significant natural resources in the site area will remain as a residual safety problem.

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INTERIM REPORT: JULY 1, 1978 TO JULY 31, 1979

DOE/NE/93023-3

REVIEW OF THE CRITERIA FOR THE SITE SUITABILITY, DESIGN, CONSTRUCTION, AND OPERATION OF THE PROPOSED WASTE ISOLATION PILOT PLANT (WIPP)

INTERIM REPORT: JULY 1, 1978 to JULY 31, 1982

Panel on the Waste Isolation Pilot Plant

BOARD ON RADIOACTIVE WASTE MANAGEMENT

Commission on Physical Sciences, Mathematics, and Resources

NATIONAL RESEARCH COUNCIL

Washington, D.C. 1983

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CONTENTS

PREFACE

In March 1978, the Department of Energy (DOE) asked the National Research Council "to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere." The National Research Council assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources.* The committee organized the Panel on the Waste Isolation Pilot Plant to "review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

In July 1978, when this study began, the Waste Isolation Pilot Plant (WIPP) was to be a mined repository in bedded salt in Eddy County, New Mexico, for the disposal of transuranic (TRU) waste, with experimental facilities for studying the interactions of high-level waste with the host rocks. At that time, use of this repository for disposal of a limited number of commercial, spent-fuel elements was also being considered, although this was not part of the project's mission. This option was discussed frequently in technical briefings of the panel and in supporting documentation. The panel has examined some of the generic issues related to this possible course of action, as well as those concerns raised solely by the proposed disposal of transuranic waste in the particular salt formations at the WIPP site.

With a few exceptions to take account of more recent information, this report recounts the panel's findings through the end of July 1982. By that time, several major WIPP program documents had been issued, including the Geological Characterization Report (Powers et al. 1978),

*Now the Board on Radioactive Waste Management under the Commission on Physical Sciences, Mathematics, and Resources.

the Title I Design Report (Bechtel National, Inc. 1979), the Final Environmental Impact Statement (U.S. Department of Energy 1980), and the Safety Analysis Report (U.S. Department of Energy 1980-1982). The present report is based on analysis of the contents of these and other documents, numerous technical briefings, extensive discussions with representatives of DOE and its contractors, comments by interested members of the public, and several field visits.

Some of the documents have been available only in draft form, some are undergoing major revision, and still others remain to be issued. Evaluation of the adequacy of criteria in the final versions of such material is a matter for future consideration by the panel. The panel expects to evaluate work through approximately December 31, 1983.

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The panel has evaluated the scientific and technical adequacy of work being done on the WIPP project to satisfy the charge to the panel set out in Chapter 1. It has found that the scientific work has been carried out with a high degree of professional competence, and that the presently unresolved hydrological and geological uncertainties about the WIPP site will not interfere with the completion of the WIPP research and development mission. With a flexible approach, there is time yet to resolve these uncertainties before large-scale transuranic (TRU) waste emplacement begins. The panel regards all WIPP facility planning and design to be provisional at the present time and subject to revisions in the light of future findings of the WIPP R&D program.

The engineering aspects of the many WIPP studies by DOE contractors have not yet reached the final stage, so our conclusions on these matters are limited.

Although the panel's conclusions and recommendations appear at the end of each chapter, they are collected in this section for the reader's convenience.

CONCLUSIONS

Chapter 2: Site Selection and Characterization

- Although the evidence now suggests that hydrocarbons and potash might be extracted from Zone IV without harm to the repository, the integrity of the repository must be the first consideration. Each proposal to develop the resources should be examined rigorously on a case-by-case basis, with the burden of proof resting with the proposer (pp. 14, 16; see also Appendix D).
- The long distance from fault displacements and basaltic eruptions in the Rio Grande Valley and the lack of evidence of major seismic events near the site seem sufficient to ensure tectonic quiescence at the site during the period of interest (p. 16).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it would not present a credible risk to the repository (pp. 16, 17).

o Evidence is good that karst-forming processes are unlikely for a period of more than a million years to disturb the repository site (pp. 17, 18).

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause them, indicate that the likelihood of encountering an old pipe or a new one forming de novo near the WIPP site is practically nonexistent (pp. 18, 19; see also Appendix E).

o Evidence seems good that because of its low permeability, high salinity, and isotopic composition the Bell Canyon Formation cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could it be responsible for extensive interstratal dissolution (p. 18, 19).

o The preponderance of evidence does not support the hypothesis that large-scale recent strata-bound dissolution might endanger a repository at the WIPP site, but evidence against the hypothesis is not conclusive (pp. 19-23).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are most likely isolated pockets of fluid not connected with or residual from recent solutions moving long distances through the formation (22, 23). Even if the WIPP-12 pressurized brine reservoir in the Castile extended directly beneath the WIPP site, this should not adversely affect the operating facility, and there is insufficient justification to delay progress on the WIPP.

Chapter 3: In-Situ Tests and Experiments

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the WIPP program (pp. 32-34).

Chapter 4: Waste-Acceptance Criteria

o The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (pp. 35, 37).

o The criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity completely (pp. 37, 38).

o If there is biological activity, the presence of sulfate in the salt makes it likely that hydrogen sulfide, rather than methane, would be the major product (pp. 37, 38).

o From the WIPP viewpoint, the quality assurance system is inadequate, in that it requires no on-site verification of conformance of package contents to the certification (pp. 39, 40).

Chapter 5: Design and Operation of Facilities

o The present plan to develop the storage areas to the south of the shafts and the experimental areas to the north of the shafts is commendable (p. 44).

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 44).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 44).

o Recently the repository design has changed from four to three shafts. The four-shaft system had a far greater degree of redundancy and flexibility, both in terms of the system and of operations, than does the three-shaft system (pp. 47, 48).

o The panel has not seen an adequate quantitative evaluation of the economic advantages of the three-shaft system that justifies forgoing the flexibility and safety of the four-shaft system (pp. 47, 48).

o The system as presently proposed with three shafts has redundancy more typical of conventional mining practice than of nuclear industry practice (p. 48).

Chapter 6: Performance Assessment

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (pp. 50, 51). (Since this analysis was completed, the lower limit of concentration for classifying transuranic wastes has been changed [9/30/82] by the Department of Energy from 10 to 100 nanocuries per gram. The amount of waste affected, the cost to handle it, and the safety consequences of this change have not yet been published).

o The long-term release scenarios, shown in Figures 6-1 to 6-6, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within prescribed limits (maximum 170 mrem whole body) and far below the dosages from normal background radiation (average 50 years, 5,000 mrem) (pp. 51-57).

RECOMMENDATIONS

Chapter 2: Site Selection and Characterization

o It is practicable to evaluate the effects of resource extraction in Zone IV on a case-by-case basis to assess whether or not such extraction poses any significant threat to the safety and integrity of the repository. Though present extraction techniques pose no significant threats to the repository, the Department of Energy should obtain the right to deny mineral and hydrocarbon extraction in Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 14, 16).

o To test the extent of deep strata-bound dissolution, Sandia's plans for further field and analytical work should be implemented. These plans include (a) making firmer estimates of the amount of salt deposited and removed by comparing in detail drill cores and borehole logs from many parts of the basin, and (b) studying in detail the water flow and residues in anhydrite beds (pp. 19, 20).

o One or both of the remaining hydrologic test holes planned to be drilled in 1983 should be located on lineaments or fracture traces if such features are revealed on satellite images and high-altitude areal photographs. Hydrologic test holes so located would help to determine if zones of fracture concentration exist within dolomite at the WIPP site and if they are influencing differential salt dissolution and/or secondary permeability development. Such narrow and elongate zones of more closely spaced fractures should exist in dolomite at the WIPP site judging from their observed presence in reef and other strata southwest of the site and elsewhere. The hydrologic significance of shorter, more numerous rock fractures, or anisotropy, have been revealed at three Rustler dolomite sites by Gonzalez (1982). The basic short-term hydrologic investigations planned and being carried out by Sandia National Laboratories to refine understanding of the nature and distribution of permeability within Rustler aquifers are well conceived and should be continued (pp. 19, 20).

Chapter 3: In-Situ Tests and Experiments

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU wastes at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU wastes (p. 32).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation. Outside developments in automated sensing, robotics, instrumentation in hostile environments, etc., should be systematically screened for application or testing at the WIPP facility (p. 33).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 33).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate the latter form of testing and thus permit expansion of the matrix by less expensive experiments (pp. 33, 34).

Chapter 4: Waste Acceptance Criteria

o As soon as feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 35).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (pp. 35, 37).

o The existing deficiency in the SAR on procedures for fighting transient underground fires should be remedied (p. 37).

o The humidity of still air in equilibrium with the salt and the pH of the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 38).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas-generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (p. 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (p. 38).

o State-of-the art equipment should be provided at the WIPP facility for nondestructive verification of compliance with those elements of the waste-acceptance criteria for which such equipment exists (p. 39).

o The existence of a practical alternative should be ensured for handling those TRU wastes that arrive at the WIPP site and that fail to meet the WIPP TRU waste-acceptance criteria. The alternative should be available at the time that it is needed (p. 40).

o Waste-acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The definition should be early enough to allow time for review before experimental operations begin (p. 40).

Chapter 5: Design and Operation of Facilities

o Explicit mechanisms for the transfer of information from SPVD experiments and information gathered during construction and development to final design must be established (p. 42).

o Displacements of the salt in the far field that occur as a result of long-term closure of excavations must be shown to be sufficiently small that they do not significantly increase the permeability of the bulk of the salt (pp. 44, 47).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 47).

o The justification for using diesel motive power for salt transport underground should be reexamined (pp. 47, 48).

o The effects of changes in the configuration of the surface facilities, the number of shafts, the ventilation system, and the electrical backup need to be further elaborated in terms of operational safety, efficiency, and nuclide releases (pp. 44, 45).

Chapter 6: Performance Assessment

o Hydrologic investigations and monitoring programs should be continued to more adequately resolve the differences between recent and initial interpretations of potentiometric maps and to provide a more consistent and confident definition of the rates and directions of groundwater flow within Rustler aquifers above and immediately adjacent to the site (pp. 56, 58).

o Though karst-type flow in the Rustler occurs near Nash Draw, the extent to which it reaches eastward is not clearly delineated. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be sharply reduced. Both the probability of such flows and their effect upon radiation dosages need to be determined (p. 58).

CHAPTER ONE

INTRODUCTION AND BACKGROUND

The history of the Waste Isolation Pilot Plant (WIPP) project was presented to this panel at a study planning session on June 5, 1978. As far back as March 1974, the Oak Ridge National Laboratory had begun site investigations for a terminal radioactive waste repository for commercial high-level waste in a region selected by the U.S. Geological Survey in the Los Medanos area of New Mexico. In May of that year, this work was suspended in favor of the concept of retrievable surface storage, and the land-withdrawal action that had been initiated was deferred in December 1974. The Albuquerque Operations Office of the U.S. Atomic Energy Commission (AEC) and the Sandia National Laboratories were then requested by AEC headquarters to become involved in the program to locate a site for a radioactive waste disposal pilot plant for defense-related low- and intermediate-level transuranic waste, with some provisions for experimentation with defense high-level waste. When drilling began in 1975 at a site in the Los Medanos region recommended by Sandia, irregular subsurface geological conditions were found, including high-pressure brines and gases. Consequently, the first site was rejected, and a new one was identified independently by Sandia National Laboratories and the U.S. Geological Survey 11.2 km to the southwest. The general location of the site and a geologic section through the Los Medanos area are shown in Figures 1-1 and 1-2, respectively. In January 1976, the geological investigations were resumed at the newly proposed site, and the project was given its present name: Waste Isolation Pilot Plant.

The drilling of ERDA-9, the first hole at the new site, commenced in April 1976. In October 1976, funding was requested for an architect-engineer, and a new land-withdrawal notice was placed in the Federal Register in December 1976. In April 1977, a preliminary version of the Draft Environmental Impact Statement was distributed by the U.S. Department of Energy (1979) for comment, and it was announced that WIPP would be a licensed facility. In June, the final version of the conceptual design was issued. In September, Bechtel was selected as the architect-engineer, and in November, the DOE sent a letter to the Nuclear Regulatory Commission saying it intended to request a license.

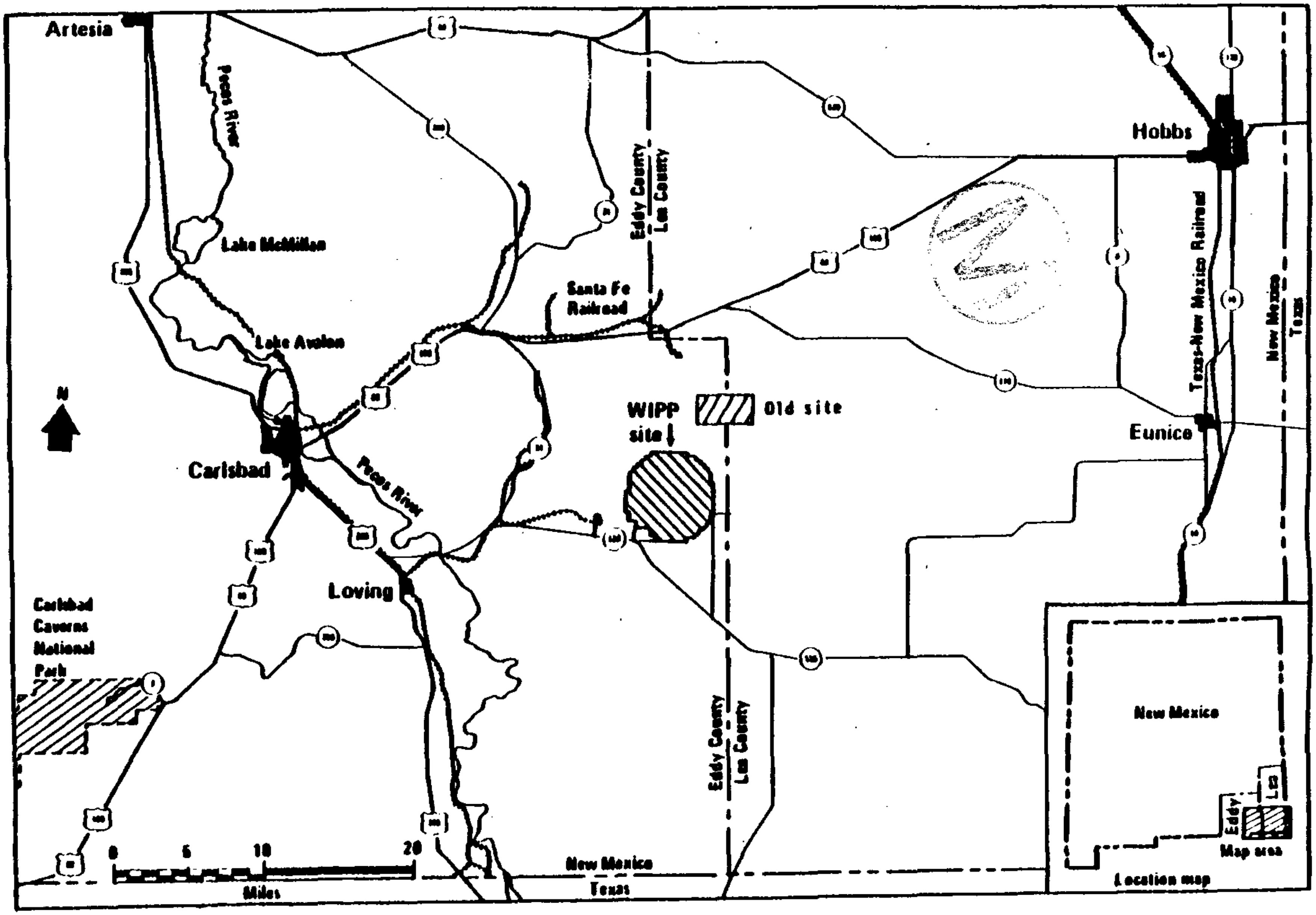


FIGURE 1-1 General location of the WIPP site. Source: U.S. Department of Energy (1980).

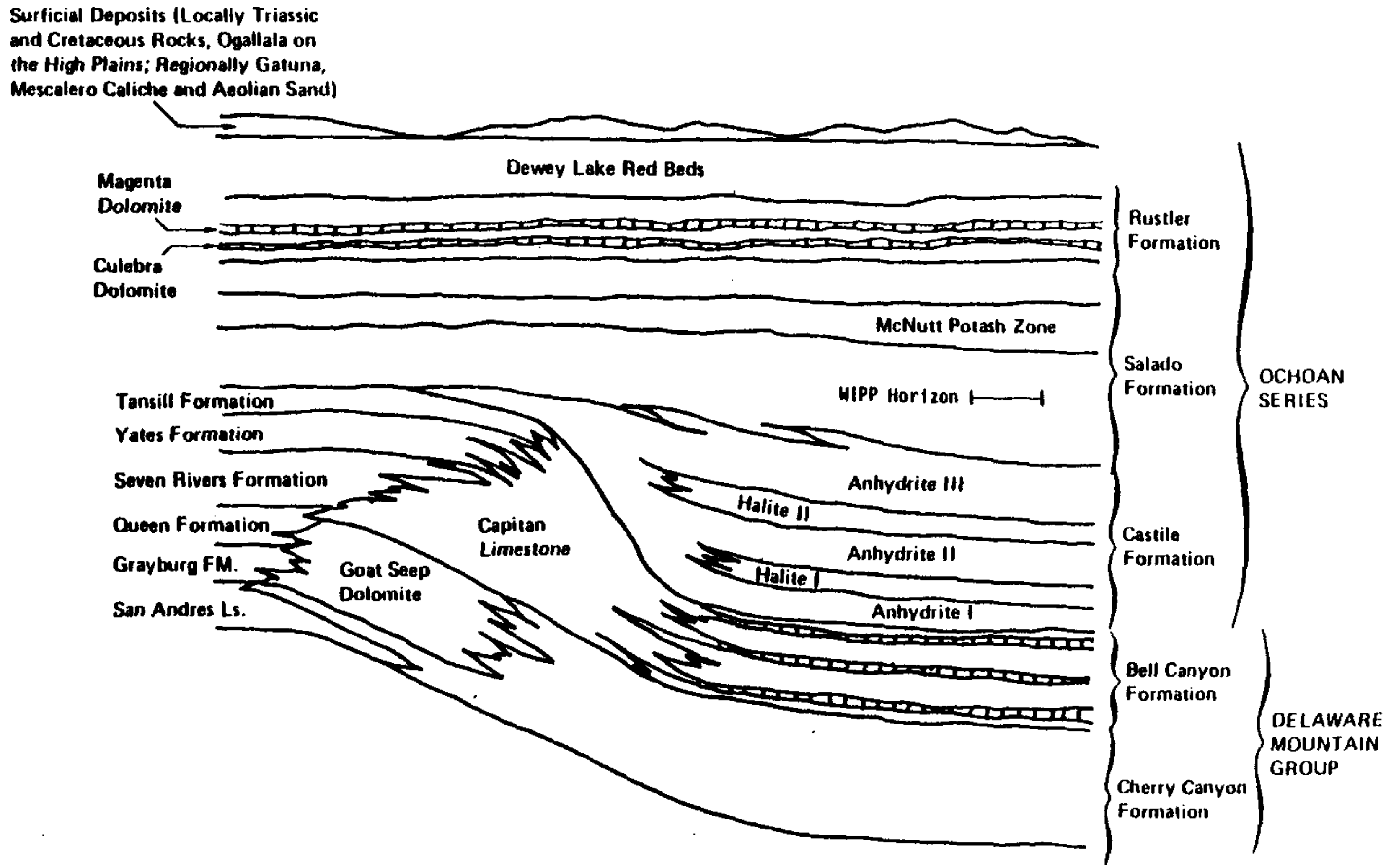


FIGURE 1-2 Diagrammatic section showing stratigraphy of the Delaware Basin. Not to scale. Source: Lambert (1982).

In February 1978, the "Deutch Report" (U.S. Department of Energy 1978) called for a demonstration of the experimental emplacement of high-level waste and possibly ultimate disposal of commercial spent fuel at the WIPP site. Objections were raised by the Committee on Armed Services, U.S. House of Representatives, which insisted that the site should be unlicensed and used only for defense waste. This view eventually prevailed.

The Geological Characterization Report (Powers et al. 1978), a compilation of geotechnical information available as of August 1978 and judged to be relevant to WIPP studies, was published in December 1978.

In March 1979, an Interagency Review Group (IRG) appointed by President Carter reported on its review of the progress of the U.S. waste disposal program and suggested four alternative technical strategies, one of which would specify salt as the host geologic medium for the first mined repository (Interagency Review Group 1979). The following month, DOE issued for public comment the WIPP Draft Environmental Impact Statement, or DEIS (U.S. Department of Energy 1979), including consideration of the possibility of disposal of limited quantities of commercial spent fuel.

Public Law 96-164, enacted in December 1979, authorized WIPP as a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission. Within three months, President Carter announced his intention to recommend cancellation of WIPP and requested rescission of previously appropriated funds. Congress did not act on the rescission request, however, and the project continued, as authorized by PL 96-164.

The WIPP Safety Analysis Report, or SAR (U.S. Department of Energy 1980-1982), was issued in February 1980 and has been updated by amendments in September 1980, January 1981, October 1981, and September 1982.

In October 1980, DOE issued a Final Environmental Impact Statement, or FEIS (U.S. Department of Energy 1980), which included responses to comments received from the public and from government agencies, and which reflected changing policies and legislative requirements. In the new document, the concept of an intermediate-scale facility for the disposal of spent fuel and the associated two-level underground layout were eliminated. Also deleted was the proposal for licensing of the repository.

Thus, as of this writing, the WIPP repository is intended as an unlicensed facility for the disposal of TRU waste generated in U.S. defense programs and for the experimental emplacement of a small quantity of high-level waste. No permanent disposal of high-level waste is planned. TRU waste, it should be noted, differs from high-level waste in that very little heat is generated. Calculations indicate that the maximum temperature rise in the center of the repository will be less than 2°C, so that the effects of heating on the salt beds will be negligible.

One of the first official acts of the Reagan administration was the January 1981 issuance of a Record of Decision to proceed with the project; but in April, the State of New Mexico filed suit against DOE to require acquisition of extensive additional technical information and the resolution of a number of controversial issues. Under the resulting Stipulated Agreement, signed in July 1981, a number of technical reports are being prepared and are being examined by the panel as they become available.

Independently of this DOE-sponsored study by the National Research Council, the State of New Mexico itself has set up four groups concerned with WIPP--an Environmental Evaluation Group (EEG); a Radioactive Waste Consultation Task Force, composed of three members of the governor's cabinet; a Radioactive Waste Consultation Committee, composed of eight members of the state legislature; and, until June 1, 1981, a Governor's Advisory Committee on WIPP.

WIPP program activities were in progress during the course of this study; thus the panel was evaluating existing data and concepts while new information was being obtained and analyzed. This report is not a summary of WIPP activities, but an analytical commentary on those aspects that the panel has reviewed. For completeness, some material has been included that was incorporated originally in three special reports (Appendices A, B, and C) that dealt with site suitability of the proposed site near Carlsbad, New Mexico, from a geological and hydrological standpoint; the limitations of surface exploration of underground formations, and continued evaluation of the Carlsbad site. A September 1981 Progress Report (National Research Council 1981) on the first 18 months of this study has also been drawn upon, as appropriate.

CHAPTER TWO

SITE SELECTION AND CHARACTERIZATION

HISTORY

The criteria that were used in selecting the WIPP site reflect the criteria commonly cited in proposals for waste isolation in bedded salt (National Research Council 1970) and the geological criteria for repositories (National Research Council 1978) and seem technically and scientifically adequate. The recommendations include (1) a bed of rock salt (halite) at least 60 m thick, of purity sufficient to minimize chemical complications from brine of complex composition and from water released from hydrous minerals; (2) a depth greater than 300 m to ensure freedom from surface influences; (3) a depth less than 1,000 m to ensure acceptably low creep rates in the salt; (4) approximate horizontality to minimize difficulty in mining operations; (5) little indication of recent tectonic or igneous activity; (6) sufficient distance from an exposed edge or underground aquifer where salt dissolution is occurring; and (7) an area without a history of resource extraction and sizable economic resources. Although many sites in the United States would probably satisfy these criteria, a site in southeastern New Mexico was chosen as described in Chapter 1.

Two additional criteria specific to the Carlsbad area were suggested by the conclusions of a study (Bradshaw and McClain 1971) at Lyons, Kansas, and by observations at an earlier WIPP site (a site near borehole ERDA-6): the repository should be located at least 1.6 km from the nearest borehole penetrating through the salt beds, and at least 8 km from the Capitan Reef to avoid a zone of disturbed bedding known to parallel the reef.

With these criteria in mind, lines were drawn on a map to outline areas where salt beds of requisite thickness at proper depths were known to occur and to exclude areas within 1.6 km of known deep boreholes, within 8 km of the Capitan Reef, within 1.6 km of the dissolution front, or with known potash or hydrocarbon resources. Two areas of reasonable size outside these lines were identified (see Figure 2-1). Site 2 seemed less suitable because it had deeper salt beds and was closer to an oil field where water flooding may be used for secondary recovery in the future, even though Site 1 was closer to the reef and the potash zone. Both sites have the advantages of nearly flat topography, an arid

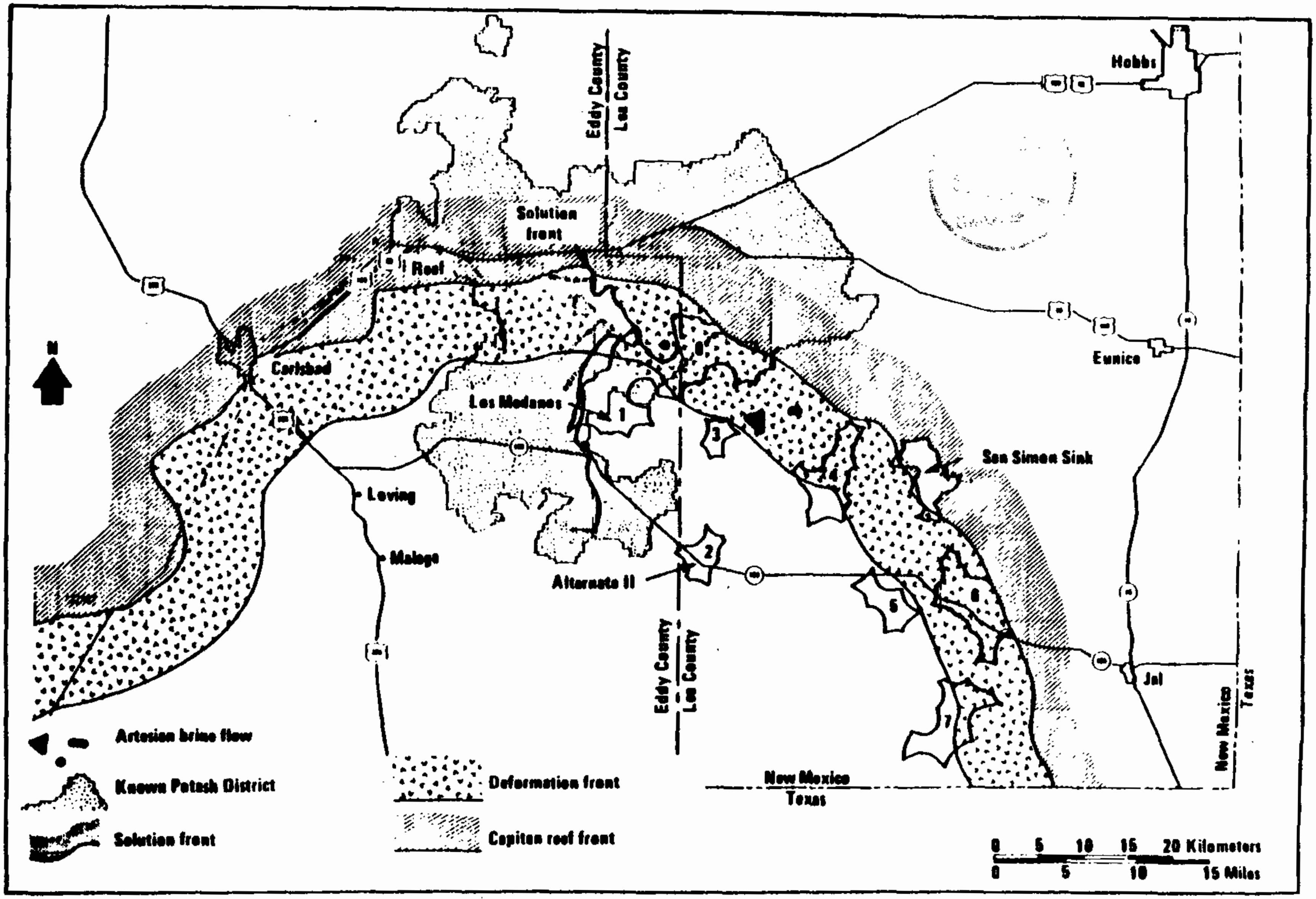


FIGURE 2-1 Application of the site-selection criteria. Source: U.S. Department of Energy (1980).

climate, and sparse population. The major regional geologic structures in the vicinity are shown in Figure 2-2.

Site 1 was chosen and subsequently an exploratory shaft was constructed. The part of the Salado Formation preselected for repository construction was mapped in great detail from exposures in the shaft. For the shaft station, a location was picked in the thickest layer of halite, containing only minor polyhalite and a few thin clay seams. The precise stratigraphic position was chosen during a technical discussion among experts from DOE and its principal contractors; personnel of the USGS and EEG were kept informed, and their comments were solicited (Jarolimek and McKinney 1982).

REMAINING UNCERTAINTIES

Although the generic criteria as applied to the WIPP site are in large measure satisfied, questions have been raised about the suitability of the site to satisfy a few of the criteria in detail. Grounds for these questions include: (1) the likely presence of economically significant quantities of potash and natural gas at the site; (2) possible tectonic instability of the site; (3) possible continued movement of the kind that produced the distorted structures in the evaporite beds of the "disturbed zone," ultimately affecting the now undisturbed beds in the middle of the WIPP site; (4) possible disturbance of the site by karst-forming processes; (5) possible local collapse of the salt beds as a result of solutions moving up from aquifers beneath the salt beds, leading to formation of vertical chimneylike masses of breccia (so-called breccia pipes); (6) possible strata-bound dissolution of salt adjacent to layers of fractured or brecciated anhydrite, especially near the Castile-Salado contact, supposedly rapid during the late Cenozoic and continuing today; and (7) possible presence of pressurized-brine reservoirs.

These objections to the WIPP site have been expressed many times over the past several years. Many of the objections have been partially answered and so have become less serious in the course of time, but valid questions remain about a few. The following discussion is focused on recent attempts to deal with the remaining questions.

Natural Resources

Further study after the site had been picked showed that probable potash and hydrocarbon resources were greater than had been thought originally, though they are still not economically worth recovering with present techniques and at current prices. Because of these resources, the ability of the site to satisfy the criterion relating to natural resource potential seemed dubious, and two years ago this question loomed as a major flaw in the case for site suitability. A recent study indicates, however, that most current techniques of mineral exploitation can be safely employed in the outer part of the site area (Zone IV, shown in Figure D-1, Appendix D) (Brausch et al. 1982), so that a large

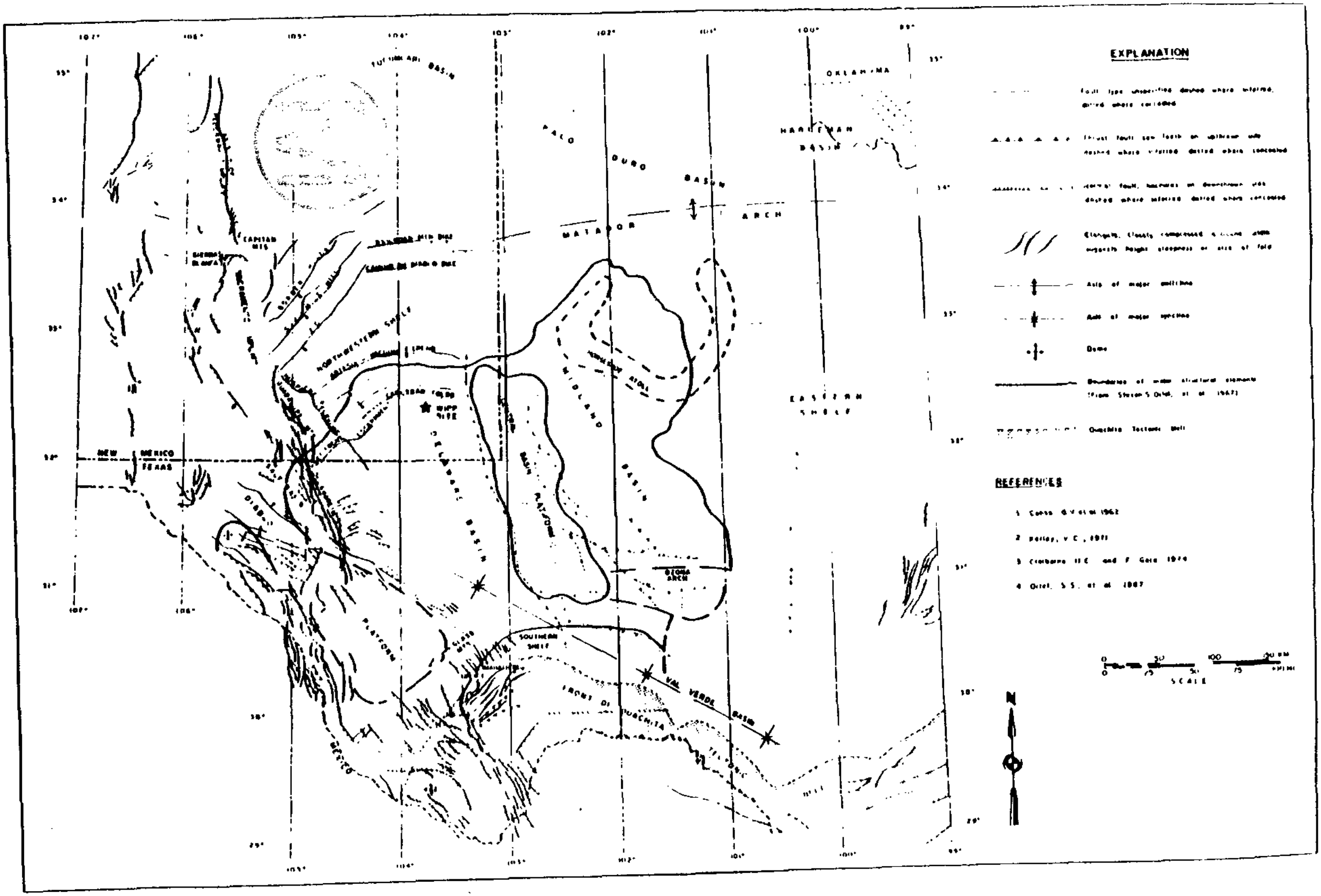


FIGURE 2-2 Major regional geologic structures. Source: U.S. Department of Energy (1980).

part of the hydrocarbon and potash resources may be recoverable with no appreciable hazard to the waste facility. The panel accepts this conclusion only with the proviso that each proposal to develop the resources should be carefully examined, with the burden of proof as to its safety made the responsibility of the proposer.

That is, subsidence and increased hydraulic conductivity due to the use of mining techniques such as hydraulic fracturing ("hydrofracking") or solution mining would not affect the integrity of the repository if these activities were restricted to Zone IV. However, this does not reduce the attractiveness of the site to future generations for mineral exploration.

More detailed discussion of the value of natural resources and the consequences of mining them is included in Appendix D.

Tectonic Stability

The well-known occurrence of fault displacements and basaltic eruptions during the Quaternary epoch in the Rio Grande Valley 250 km west of the site was cited a few years ago as posing a possible risk of future tectonic disturbance at the waste facility. The risk is not wholly negligible, of course, but to most observers the long distance from the Rio Grande coupled with complete absence of seismic evidence for significant crustal movement and of geologic evidence for recent tectonic disturbance or volcanic activity has seemed sufficient to assure tectonic quiescence at the site. The only recent evidence bearing on the question is simply the continued lack of anything but very minor seismic events recorded by the seismic network established near the site.

The "Disturbed Zone"

The "disturbed zone" is an area adjacent to the Capitan Reef in the northern and eastern parts of the Delaware Basin in which evaporite beds are deformed, as shown by borehole data and seismic profiles. The deformed beds are in part strongly tilted, folded, and faulted, and in places show marked increases and decreases of their normal thickness. In general, the intensity of deformation decreases away from the Capitan Reef, and at the distance of the WIPP site is relatively mild. Deformed rocks at the margin of the disturbed zone have been encountered in boreholes in the northern part of the WIPP area, and stronger deformation is found beyond its borders to the northeast. In addition to the disturbed zone, small isolated areas of somewhat deformed rocks occur elsewhere in the basin, but none within 3 miles of the WIPP site.

Concern has been expressed about the possibility that deformation may be continuing today, and may affect the presently almost undisturbed strata in the middle of the WIPP site at some time in the future. Strong movements in the beds containing a waste facility, it is feared, might disrupt the stored waste and permit entry of solutions that could dissolve and transport some of the radioactive material.

To investigate this possibility, an intensive study of deformation processes in the salt beds has been undertaken (Borns et al. 1983). The study includes detailed descriptions of the kinds of deformation present, evidence regarding the age of deformation, and discussion of several hypotheses of origin. Although the authors conclude that evidence is insufficient to give a firm date for the time (or times) of deformation or to establish beyond question the mechanism by which the deformation occurred, they note that by any reasonable hypothesis of origin, the time involved in forming the observed structures is very long, on the order of a million years or more. Hence, the deformation, even if it is continuing now, would not "present a major hazard to the construction and operational stages of the facility." Later deformation might result in minor distortion of a repository, but according to Borns et al. (1983), this would not lead to appreciable movement of radionuclides because there is no evidence for involvement of solutions in the deformation at this horizon beyond small amounts of interstitial fluids.

Karst-forming Processes

The Los Medanos region, like other areas of the world underlain by soluble rocks, is subject to locally rapid and potentially widespread dissolution wherever undersaturated solutions come in contact with the rocks beneath. The dissolution in part works down from the surface and in part is caused by groundwater moving through permeable beds and channels below the surface. As parts of the rock dissolve, overlying material collapses into the open spaces. The result is a distinctive kind of topography called karst, characterized by sinkholes, caves, valleys without stream channels, and underground drainage (Bachman 1980, p. 46)--features prominently displayed in parts of southeastern New Mexico near the WIPP site. Although no karst features have been noted at the site itself, the presence of such features within several kilometers, particularly in Nash Draw (about 10 km west of the site) has led to worry that karst may work its way into the site in the near geologic future and provide pathways for water to reach a subsurface waste facility.

Dissolution is clearly in progress on the uptilted edges of the evaporite beds in the western part of the Delaware Basin, and can be expected to work its way slowly eastward. Important questions, then, concern the rate of present dissolution and possible future changes in the rate due to climatic change or tectonic disturbance.

The rate of dissolution has been estimated in various ways. In Nash Draw, where geologically recent dissolution has removed much of the Rustler Formation and part of the upper Salado, two Pleistocene formations, the Gatuna and the Mescalero, in part lie undisturbed on an old karst surface and in part have collapsed as a result of continuing dissolution. From these facts Bachman (1980) concludes that present karst features have formed during and since the deposition of these beds. The older one (Gatuna) can be confidently dated (from an included bed of volcanic ash) as about 600,000 years old, and from the thickness of evaporite strata removed since Gatuna time, Bachman derives an average rate of vertical dissolution of 10 cm in 1,000 years. A similar figure has been estimated from the amount of salt currently being dissolved and discharged by streams and springs in the basin (U.S. Department of Energy 1980, p. 7-98). For the rate of horizontal dissolution, Bachman and Johnson (1973) estimated 10 to 13 km per million years, on the assumption that "at the end of Ogallala time the Salado Formation extended to the Capitan Reef on the western edge of the basin." These estimates suggest that a waste facility at the WIPP site should be secure from karst-forming processes for at least a million years.

Implicit in this conclusion is the assumption that the future climate of southeastern New Mexico will be similar to the average climate over the past 600,000 years. During this period in the past, the climate has fluctuated from dry to pluvial, but on the whole has been fairly arid. There is little reason to expect that average climates in the future will deviate greatly from this pattern (Bachman 1980); nor is it likely, as noted in the last section, that tectonic movement in the next few hundred thousand years will elevate this region sufficiently to cause a marked change in average rainfall.

The panel recognizes that estimates of dissolution rates and guesses about future climates are based on somewhat slender evidence, but the assumptions involved seem reasonably conservative, and the general conclusion that a repository at the WIPP site would not be disturbed by karst-forming processes for a million years or more seems well founded.

Breccia Pipes

The possibility of forming vertical pipelike masses of breccia by collapse induced by solutions working their way upward into the repository in the salt beds from aquifers beneath, similar to breccia pipes observed elswhere in the basin, has been raised repeatedly over the past several years (Anderson and Kirkland 1980; Anderson 1981a, b). Two years ago the favored form of this hypothesis envisioned solutions in the Bell Canyon Formation (of the Delaware Mountain Group below the evaporite beds) as the active agents of dissolution, and postulated that the solutions not only formed the collapse pipes, but also worked their way along the Castile-Salado contact, dissolving the lower Salado salt (in which the repository would be sited) as they moved. In other words, at that time a combination of the fifth and sixth uncertainties mentioned previously was proposed--active formation of breccia pipes and widespread dissolution of salt in the lower Salado, in part by solutions rising into the pipes from below.

More recently, the formation of breccia pipes near the waste facility has been shown to be highly improbable, and the Bell Canyon Formation has been proved incapable of generating solutions that could either form breccia pipes or cause widespread dissolution (Lambert 1982; Wood et al. 1982). Demonstration that formation of breccia pipes poses no appreciable hazard to the WIPP site depends on a recent theoretical argument and additional field data. Until recently the formation of breccia pipes has been attributed to a mechanism of "density flow"--the rise of unsaturated solutions into overlying salt beds, the dissolving of salt to form more saturated and hence more dense solutions, and the descent of these dense solutions to make room for fresh injections of unsaturated fluid (Anderson and Kirkland 1980). On theoretical grounds this mechanism could produce pipes of collapsed material only if dissolution at the base of the salt section is fairly rapid. With fast-enough dissolving of salt, a cavity or zone of weakness might be produced into which overlying beds would collapse by brittle fracture; but if the dissolving is slow, the salt would gradually subside by plastic flow to form a funnel-shaped volume of somewhat deformed beds rather than a pipe of brecciated salt (Davies 1983). Rapid dissolution at the WIPP site could only be caused by fluids in the Bell Canyon Formation, which immediately underlies the salt. Recent data on this formation, however, indicate that it is not a credible source of such fluids: The permeability of this formation is low and practically restricted to a few small sand stringers with little hydraulic interconnection; the amount of water is small, it moves only slowly, and it contains too much dissolved material to be an effective solvent (Lambert 1982, p. 119). Spiegler (1982), using reasonable numbers for the properties of salt and the solutions in the Bell Canyon, has calculated that the rate of plastic flow of salt would be on the order of a hundred times its rate of removal by dissolution.

A more likely cause of breccia pipes is sudden collapse into an opening dissolved out of an underlying brittle rock such as limestone. All known pipes in the Los Medanos area have been shown to exist only in places where the salt beds overlie parts of the limestone of the Capitan Reef; and the near certainty that collapse originated in the limestone has been established by deep drilling in one of the pipes that showed breccia persisting downward to the bottom of the drill hole, only a few meters above the reef (Snyder and Gard 1982).

Since the WIPP site is 8 km from the nearest part of the reef, and since solutions in the Bell Canyon Formation are unlikely to cause sudden collapse in the salt itself, the formerly suggested danger of encountering an old pipe at the WIPP site, or of a pipe forming de novo under the waste facility, seems remote. More details on breccia pipes are found in Appendix E.

Deep Strata-bound Dissolution

Anderson has continued to express concern about possible extensive deep interstratal dissolution caused by solutions generated by infiltration of meteoric water, moving long distances through layers of fractured anhydrite near the Castile-Salado contact and dissolving halite from the beds above and below (Anderson 1982a). The evidence for such dissolution is chiefly the absence of much of the lower Salado salt under the western part of the basin (Anderson 1981b, 1982a; Anderson et al. 1972). The amount of missing salt was estimated by extrapolating salt thicknesses, from areas where salt is believed to be intact to areas where salt is thinned or missing. Detailed matching of fine laminations ("varves") in the evaporite sequence, particularly in anhydrite beds, in cores from drillholes at intervals across the site, indicated that Salado salt was originally deposited throughout the Delaware Basin. The gap in the salt sequence is thought to be due to dissolution; the anhydrite breccias ("dissolution breccias" formed as residues of salt dissolution) in some of the cores from the western half of the basin are cited as further evidence. It is thought that some of the surface depressions above the supposed dissolution front were formed by subsidence due to dissolving out of salt beneath, and from failure to find sediments older than Pleistocene in these depressions, Anderson concludes that rapid dissolution is limited to the past few million years and is probably continuing today. Water for dissolving the salt is assumed to be of meteoric origin (Anderson 1982a). It descends into the upturned salt edge in the western part of the basin, traverses layers of fractured and brecciated anhydrite near the Castile-Salado contact, and leaves the basin through cavities in the buried Capitan Reef on the east side. The brine reservoirs encountered in the ERDA-6 and WIPP-12 drillholes are cited by Anderson as ponded remnants of the solutions that have moved, or are moving, through the brecciated anhydrite layers.

The validity of this hypothesis is difficult to judge against alternative ideas. Scientists at Sandia National Laboratories agree that strata-bound dissolution of the sort described above is possible, and may well be responsible for formation of some of the surface depressions in the Los Medanos area (Lambert 1982). They disagree with regard to the scale and recency of the dissolution process. The earlier hypothesis envisions solutions moving completely through the evaporite basin to the Capitan Reef, concentrated in strata near the Castile-Salado boundary, and active primarily in the last few million years. By contrast, the Sandia scientists consider strata-bound dissolution to be a relatively minor process today and in the recent geologic past; they think of it rather as a phenomenon that was active adjacent to many anhydrite beds at various times since the Permian, is restricted to the western part of the basin, and is limited in its range by escape of the solutions into various debris-filled depressions. In the previous hypothesis the dissolution is active enough and extensive enough to be a serious threat to a waste facility at the WIPP site; to the Sandia scientists, the interstratal dissolution is simply a minor part of the slow, general dissolution of the evaporite sequence that has gone on intermittently for hundreds of millions of years and poses no appreciable hazard to the proposed facility.

A choice between the two viewpoints must rest on answers to several subsidiary questions: (1) What is the magnitude of salt removal, particularly from the lower Salado? (2) Can actual movement of large volumes of fluid through anhydrite beds near the Castile-Salado contact be demonstrated, either as present-day movement or movement in the recent geologic past? (3) What is the evidence for major dissolution in the late Cenozoic, as opposed to dissolution at intervals since the Permian?

(1) Amount of Salt Removed

That some of the thick, lower Salado halite present in the eastern part of the basin is missing toward the west is well established, but explanations for its absence differ. Anderson, in support of his hypothesis, estimates the amount of missing salt by painstaking comparison of many tens of thousands of thin stratigraphic units based on geophysical logs in drillcores from boreholes across the basin, and ascribes the absence of salt entirely to removal by geologically recent dissolution (Anderson et al. 1972). Lambert (Lambert 1982, Chapter IX) questions the validity of some of the stratigraphic correlations, and attributes the missing part of the salt sequence to several phenomena: nondeposition of halite on elevated parts of the original evaporite basin, deposition of anhydrite rather than halite in parts of some continuous beds (as is common in evaporite sequences elsewhere), removal of some halite by erosion during the Permian (as evidenced by an unconformity separating parts of the Castile and Salado), and removal of some halite by dissolution at several periods since the Permian. A clear-cut choice between the two views is not possible on the basis of present knowledge, but a detailed review of borehole cores and geophysical logs being undertaken by Sandia will probably provide the additional information for a resolution of the conflicting hypotheses.

(2) Movement of Fluid Through Anhydrite

Anderson (1982b) regards brine reservoirs like those encountered in Castile anhydrites in the ERDA-6 and WIPP-12 boreholes as prime evidence for his present hypothesis. The brine reservoirs, in his view, are isolated pockets containing samples of the solutions that have moved or perhaps are moving through the anhydrite layers. As a source for the dissolution fluids, Anderson suggests either rainfall in an area of gravels near the west margin of the Delaware Basin (Black River gravels) or water from the Pecos River where it crosses the uptilted Salado-Castile contact; as a sink for the solutions he proposes the cavernous Capitan Reef limestone on the east and northeast sides of the basin. Lambert (1982) argues, on the other hand, that analysis of the brines in the reservoirs shows that they cannot be the result of simple dissolution of halite, because neither the observed chemical composition nor isotopic composition would result from such a process. It was also pointed out that fractured anhydrite lacks some expected characteristics of a dissolution breccia (no concentration of residual clay minerals and none of the gypsum that should form if water-filled open spaces develop in anhydrite) and is more likely produced by deformation of the salt beds. He regards the brine reservoirs as pockets of brecciated material created by slight movement in the salt layers near the edge of the "disturbed zone" adjoining the Capitan Reef; the brine has accumulated from a variety of sources, perhaps largely by "kneading out" of fluids from halite beds during deformation (Borns et al. 1983), and remains immobile. The facts that the brine reservoirs have pressures well above hydrostatic, that flow of solutions from one reservoir has no effect on nearby reservoirs, and that anhydrite from most boreholes that penetrate this horizon is not fractured and contains no fluids, are good evidence that the reservoirs are not part of a widespread interconnected aquifer, at least not one at the present time. As an additional test of Anderson's views, scientists at Sandia National Laboratories plan a study of the detailed characteristics of residual breccias formed by dissolution, to establish criteria for distinguishing such breccias from similar fractured material produced by salt movement; anhydrite for the study will come from residual breccias higher in the evaporite sequence where dissolution is known to be taking place.

(3) Dissolution Limited Chiefly to the Quaternary

Anderson (1981a, b) grants that some salt dissolution has taken place at various times since the Permian, but contends that the major part is geologically recent and hence is probably active at present. This conclusion is based on two kinds of evidence: the supposed recency of the eastward tilting of beds in the Delaware Basin (late Tertiary), which triggered the dissolution, and the supposed lack of sediments older than Pleistocene in depressions whose origin is ascribed to dissolution of the salt beneath. The Sandia workers (Lambert 1982; Powers 1982) counter that the time of tilting of the evaporite beds is uncertain, but if it is part of the widespread disturbance that formed basin-and-range structures in the western states, it should be dated as mid-Tertiary rather than late Tertiary. They point out also that little is actually known about the age of deposits in depressions in the Los Medanos area; certainly the depressions contain Pleistocene sediments, but these sediments may conceal older beds beneath. Information about maximum age of the depression fills might be obtainable from boreholes drilled for this purpose; but datable material is so scarce in such sediments that definitive dating might require many boreholes, and it can be questioned whether the expense of such an enterprise would be justified. A clear decision about the timing of most salt dissolution seems impossible on the basis of presently available evidence. Further information on salt dissolution is found in Appendix F.

Because clear evidence for salt removal from the lower Salado is found 20 miles south of the WIPP site itself, because evidence for major dissolution in the late Cenozoic rests on the questionable Quaternary age of the entire thickness of sedimentary fill in solution basins, and because no adequate sink for postulated dissolution brines of the present day has been located, the panel doubts that deep dissolution, even if it is occurring as Anderson supposes, is progressing fast enough to jeopardize the integrity of a repository within the next million years.

Pressurized-Brine Reservoirs

Pressurized brine accompanied by carbon dioxide, methane, and hydrogen sulfide has been encountered in several wells penetrating the Castile

Formation (Griswold 1980; ▯egister 1981). The brine occurs in fractured anhydrite in places where the salt beds are deformed, most of them in the zone of deformation near the Capitan Reef. An especially large brine pocket [estimated volume 2.7 x 10^6 m^3 (17 x 10^6 bbl)] was encountered during the deepening of drillhole WIPP-12 in November 1981, only about 1 mile north of the projected repository site, and this finding has led to concern that (1) the brine in this and other reservoirs may be part of an interconnected flow of brine through the anhydrite layer, and (2) a similar large reservoir may exist at or near the repository site and could cause flooding of the repository.

Investigation of the WIPP-12 occurrence, together with previous studies of other brine pockets, has shown that such concerns are without substance (Wood et al. 1982). The principal lines of evidence are the following:

- In the Salado Formation (in which the repository is to be constructed), no brine pockets have been found except small ones at low pressures.
- The chemical and isotopic composition of brines in different reservoirs is different from one to another, and also different from the composition of groundwater in aquifers above and below the salt beds.
- Brine pockets can be emptied by allowing the brine to flow.
- Salt beds are undeformed at the repository site.
- Even if the reservoir found in WIPP-12 should extend under the repository site, or if another reservoir should exist at the site, the anhydrite layer is 244 m (800 ft) below the proposed repository horizon in the Salado Formation.

On the basis of this evidence, the panel concludes that brine reservoirs do not pose a threat to the integrity of a repository at the selected site.

SUMMARY

The panel believes that the criteria used to show that there is little appreciable hazard to a waste facility at the WIPP site from breccia pipes, tectonic disturbance, brine pockets, or extension of the "disturbed zone" are sufficient. If the hydrocarbon and potash resources at the site prove to be economic, with proper limitations much of the resources can be recovered without hazard to the repository. The preponderance of evidence, in the panel's opinion, does not support Anderson's hypothesis of large-scale, recent strata-bound dissolution that might endanger a repository at the WIPP site, but the evidence against the hypothesis is not conclusive. Further analytical and field work are necessary to make firmer estimates of the amounts of salt deposited and removed by comparing in detail drillcores and borehole logs from many parts of the basin. In addition, definitive evidence regarding water flow and dissolution residues in anhydrite beds is needed.

CONCLUSIONS

o Although the evidence now suggests that hydrocarbons and potash might be extracted from Zone IV without harm to the repository, the integrity of the repository must be the first consideration. Each proposal to develop the resources should be examined rigorously on a case-by-case basis, with the burden of proof resting with the proposer (pp. 14, 16; see also Appendix D).

o The long distance from fault displacements and basaltic eruptions in the Rio Grande Valley and the lack of evidence of major seismic events near the site seem sufficient to ensure tectonic quiescence at the site during the period of interest (p. 16).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it would not present a credible risk to the repository (pp. 16, 17).

o Evidence is good that karst-forming processes are unlikely for a period of more than a million years to disturb the repository site (pp. 17, 18).

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause them, indicate that the likelihood of encountering an old pipe or a new one forming de novo near the WIPP site is practically nonexistent (pp. 18, 19; see also Appendix E).

o Evidence seems good that because of its low permeability, high salinity, and isotopic composition the Bell Canyon Formation cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could it be responsible for extensive interstratal dissolution (p. 18, 19).

o The preponderance of evidence does not support the hypothesis that large-scale recent strata-bound dissolution might endanger a repository at the WIPP site, but evidence against the hypothesis is not conclusive (pp. 19-23).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are most likely isolated pockets of fluid not connected with or residual from recent solutions moving long distances through the formation (22, 23). Even if the WIPP-12 pressurized brine reservoir in the Castile extended directly beneath the WIPP site, this should not adversely affect the operating facility, and there is insufficient justification to delay progress on the WIPP.

RECOMMENDATIONS

o It is practicable to evaluate the effects of resource extraction in Zone IV on a case-by-case basis to assess whether or not such extraction poses any significant threat to the safety and integrity of the repository. Though present extraction techniques pose no significant threats to the repository, the Department of Energy should obtain the right to deny mineral and hydrocarbon extraction in Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 14, 16).

o To test the extent of deep strata-bound dissolution, Sandia's plans for further field and analytical work should be implemented. These plans include (a) making firmer estimates of the amount of salt deposited and removed by comparing in detail drill cores and borehole logs from many parts of the basin, and (b) studying in detail the water flow and residues in anhydrite beds (pp. 19, 20).

o One or both of the remaining hydrologic test holes planned to be drilled in 1983 should be located on lineaments or fracture traces if such features are revealed on satellite images and high-altitude areal photographs. Hydrologic test holes so located would help to determine if zones of fracture concentration exist within dolomite at the WIPP site and if they are influencing differential salt dissolution and/or secondary permeability development. Such narrow and elongate zones of more closely spaced fractures should exist in dolomite at the WIPP site judging from their observed presence in reef and other strata southwest of the site and elsewhere. The hydrologic significance of shorter, more numerous rock fractures, or anisotropy, have been revealed at three Rustler dolomite sites by Gonzalez (1982). The basic short-term hydrologic investigations planned and being carried out by Sandia National Laboratories to refine understanding of the nature and distribution of permeability within Rustler aquifers are well conceived and should be continued (pp. 19, 20).

CHAPTER THREE

IN-SITU TESTS AND EXPERIMENTS

THE WIPP R&D PROGRAM

The WIPP R&D program seeks answers to questions about repository development and waste package interactions, as shown in Table 3-1 (Matalucci et al. 1982). This program consists of projects for verification of the various models, laboratory and field testing of components, and in-situ tests with and without radioactivity. The initial phase of the in-situ tests, termed Site and Preliminary Design Validation (SPDV), consists of certain geomechanical measurements to be made underground from two shafts and an experimental area. As of August 1982 the shaft borings had been completed and geomechanical test instruments were being installed for the SPDV measurement program, scheduled to commence in late 1982.

A variety of in-situ experiments are planned for the WIPP R&D program (Table 3-2) extending to the 1990s (Table 3-3), to be carried out in a special area (Figure 3-1). Although planning for and design of the eventual construction and operation of the WIPP facility for permanent disposal of defense-generated transuranic (TRU) wastes is already underway (U.S. Department of Energy 1980-1982) and discussions for its layout are in progress (Rockwell International 1982), the WIPP facility design is subject to change, depending on findings from the in-situ tests. Even the abandonment of the WIPP site altogether would be possible if the findings prove that permanent disposal of TRU waste is not feasible at the WIPP site. The panel regards all WIPP facility planning and design to be provisional at the present time and subject to revision in the light of future findings of the WIPP R&D program. Therefore, the panel has directed its attention to the adequacy of the R&D program for providing the information needed to construct and to ensure the safety of an adequate WIPP facility.

THE SPDV PHASE

As described in sections 8.2.1 and 8.9.1 of the FEIS (U.S. Department of Energy 1980), two underground shafts have been constructed for in-situ testing in the SPDV program. These shafts, which were sunk in

TABLE 3-1 WIPP R&D Program

	TECHNICAL DEVELOPMENT			IN SITU TESTS WITHOUT RADIOACTIVITY			IN SITU TESTS WITH RADIOACTIVITY		
	MODEL DEVELOPMENT	LAB TESTING	FIELD TESTING	SPDV	TECHNOLOGY EXPS (TEs)	TECHNOLOGY DEMO	RADIATION-SOURCE EXPS (RSEs)	DHLW TESTS	TECHNOLOGY DEMO
SITE CHARACTERIZATION AND EVALUATION	●	●	●	●					
REPOSITORY DEVELOPMENT									
THERMAL/STRUCTURAL INTERACTIONS	●	●	●	●	●				
PLUGGING AND SEALING	●	●	●		●				
OPERATIONS		●	●			●			●
WASTE PACKAGE INTERACTIONS									
WASTE PACKAGE PERFORMANCE	●	●	●		●		●	●	
NEAR-FIELD EFFECTS	●	●	●		●		●		

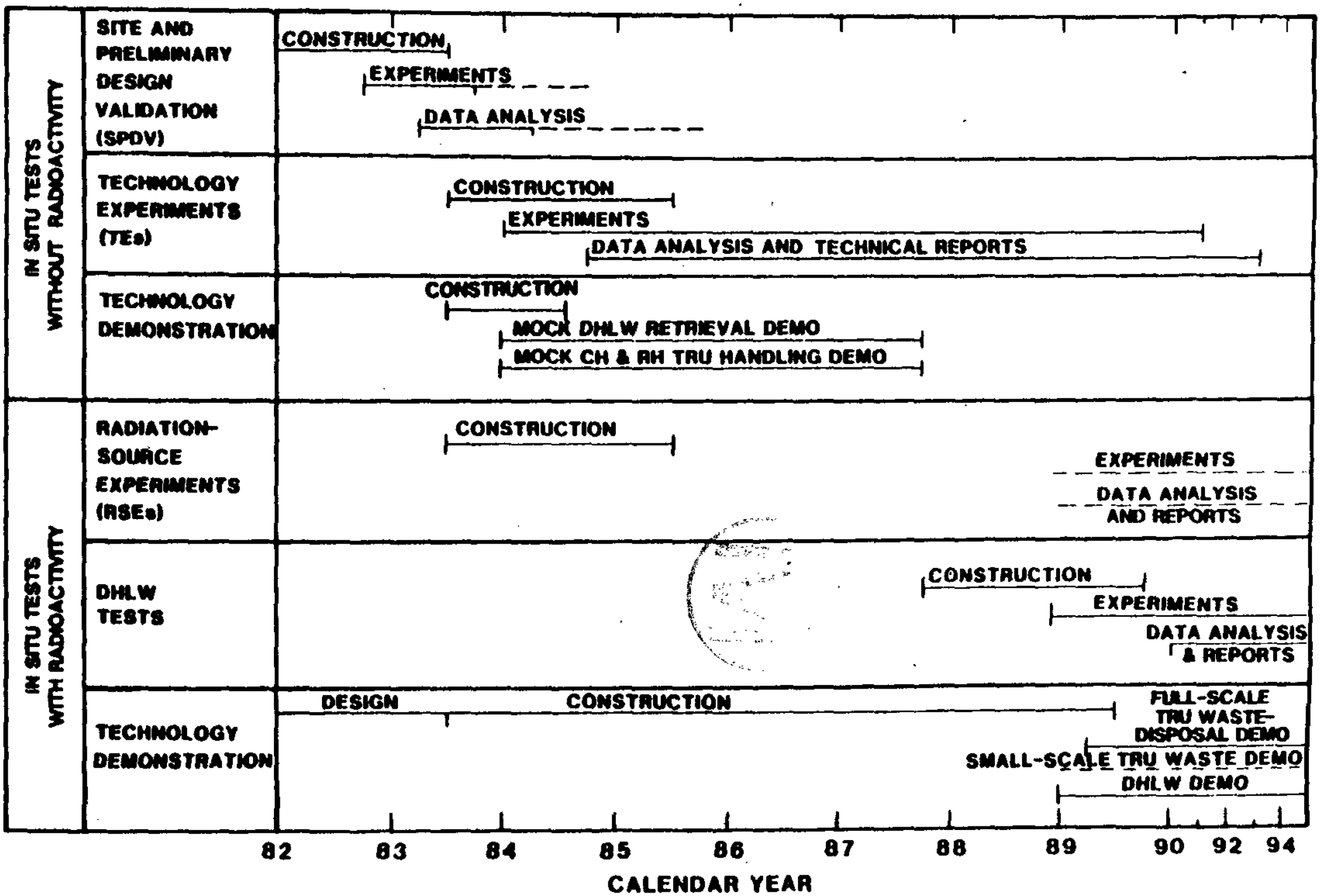
SOURCE: Matalucci et al. (1982).

TABLE 3-2 WIPP In-Situ Tests

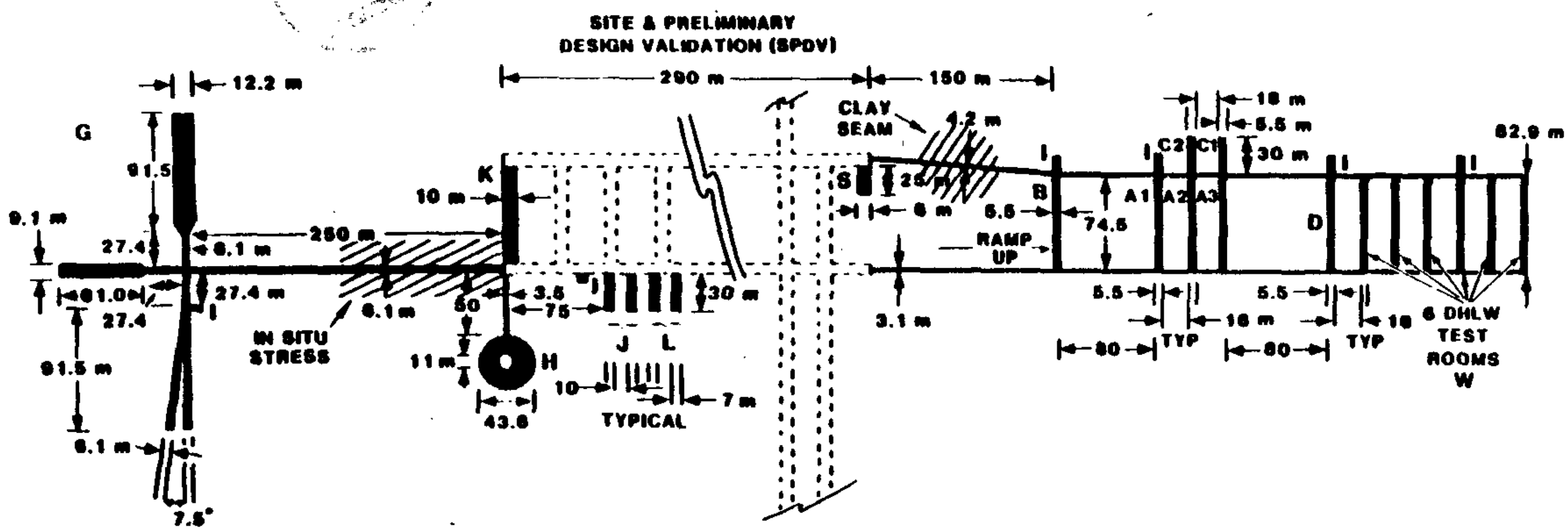
	WITHOUT RADIOACTIVITY			WITH RADIOACTIVITY		
	SPDV	TECHNOLOGY EXPERIMENTS	DEMONSTRATIONS	RADIATION-SOURCE EXPERIMENTS (OPTIONAL)	DHLW TESTS	DEMONSTRATIONS
SITE CHARACTERIZATION AND EVALUATION	• SITE VALIDATION INVESTIGATION					
REPOSITORY DEVELOPMENT						
THERMAL/STRUCTURAL INTERACTIONS	• PRELIMINARY DESIGN VALIDATION	• 12 W/m^2 MOCKUP • DHLW OVERTEST • GEOMECHANICAL EVALUATION • HEATED AXISYMMETRIC PILLAR • IN SITU STRESS FIELD • DIRECT SHEAR OF CLAY SEAM				
PLUGGING AND SEALING		• PERMEABILITY MEASUREMENTS • SIZE EFFECTS • PLUG TEST MATRIX				
OPERATIONS			• MOCK DHLW EMPLACEMENT AND RETRIEVAL • MOCK TRU WASTE HANDLING			• SMALL-SCALE TRU WASTE (OPTIONAL) • FULL-SCALE TRU WASTE DISPOSAL • DHLW EMPLACEMENT AND RETRIEVAL
WASTE PACKAGE INTERACTIONS						
WASTE PACKAGE PERFORMANCE		• SIMULATED-WASTE PACKAGE PERFORMANCE • SIMULATED-TRU-WASTE DRUM DURABILITY		• RADIOACTIVE-WASTE PACKAGE PERFORMANCE	• DHLW TESTS	
NEAR-FIELD EFFECTS		• BRINE MIGRATION (THERMAL)		• BRINE MIGRATION (THERMAL AND RADIATION)		

SOURCE: Matalucci et al. (1982).

TABLE 3-3 Schedule for WIPP In-Situ Tests



SOURCE: Matalucci et al. (1982).



NOTES:

G. THE GEOMECHANICAL EVALUATION TESTS ARE ILLUSTRATED AS ONE TEST CONFIGURATION, BUT THEY CAN BE MODIFIED OR SEGREGATED INTO SEPARATE TESTS AT DIFFERENT LOCATIONS. FINAL CONFIGURATION WILL DEPEND ON FURTHER DESIGN CONSIDERATIONS.

I. INSTRUMENTATION ALCOVES
(5 m WIDE, 10 m LONG, 3.1 m HIGH, TYPICAL)

S. WORKSHOP ALCOVE

(ALL DIMENSIONS IN METRES)

TESTS:

A. 12 W/m^2 MOCKUP
B. DHLW OVERTEST
C. MOCK DHLW EMPLACEMENT/RETRIEVAL DEMO
D. RADIATION-SOURCE EXPERIMENTS
G. GEOMECHANICAL EVALUATION
H. HEATED PILLAR
J. TRU DRUM DURABILITY (CH)
K. MOCK TRU DEMO (CH AND RH)
L. PLUGGING AND SEALING
W. DHLW TESTS

FIGURE 3-1 Layout of WIPP in-situ tests. Source: Matalucci et al. (1982).

accordance with a previous recommendation by the panel (Appendix B), are 3.7 m (12 ft) and 1.8 m (6 ft) in diameter, about 700 m (2,300 ft) and 670 m (2,200 ft) deep, respectively, and extending more than 411 m (1,350 ft) into the 610 m (2,000 ft)-thick Salado salt formation (Figure 1-2). The SPDV underground experimental area at the facility depth adjacent to the shafts is not yet constructed.

Because the mechanical properties of the salt are considered by DOE to be important for facility design, geomechanical experiments have been given the first priority for in-situ testing and are the only tests planned in the SPDV phase. These consist of convergence and radial motion measurements of the shafts, piezometers for water pressure build-up behind the shaft liner, strain measurements in unlined sections of the shaft, optional monitoring of shaft key loading and strain at the contact of the Salado salt with overlying Rustler Formation, survey measurements at geometric grid points, and geologic mapping of lithology and structure. Matalucci et al. (1982) expect the SPDV tests to meet the following objectives:

- To validate the design for the WIPP access shafts and TRU waste disposal demonstration rooms.
- To evaluate the amount and rate of shaft convergence and room creep deformation and to correlate these data with model predictions.
- To perform a preliminary evaluation of creep in salt and of the steady-state creep model.
- To evaluate instrumentation systems for accuracy and the reliability of measurements made with them in rock salt and to document the suitability of the system for future measurements.
- To evaluate the response of the in-situ formations such as clay seams and other material layers in addition to the salt.
- To collect a large number of samples of rock salt and other materials and to conduct laboratory and bench-scale tests to determine the mechanical properties of these samples.

Tests of interaction between waste and surrounding rock will follow the SPDV phase.

The WIPP design has to allow for long-term repository closure ($>$ 200 years) by plastic flow and short-term access ($\leq$ 20 years) for waste package emplacement and retrieval. A key problem of the SPDV is to verify by very short-term measurement ($\sim$2 years) that predictions from the (two-dimensional computer program) model of repository behavior over the long term are correct. The SPDV implies that this is a routine check, with little expectation of surprises. Longer-term observations will be needed to confirm that the design requirements will really be met.

IN-SITU TESTING PLAN

Bedded salt is a prime candidate to be the geologic medium for the emplacement of high-level radioactive wastes, both civilian and military. The main information presently available on such emplacement comes from Project Salt Vault, a program begun in 1963 by the Oak Ridge National Laboratory using canister and instrumentation technology of the time in a salt mine. The WIPP facility offers an opportunity for professionally executed emplacement experiments, using present waste form concepts and equipment, in an actual repository operation. This will be possible years before any comparable repository is available. Results of experiments with high-level waste in WIPP can bring decisive experience to the design of future repositories. Consequently, the opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the Waste Isolation Pilot Plant (WIPP) program.

Plans have been formulated and reported by V. F. Likar (1979) and Matalucci et al. (1982) for an R&D program that includes emplacement and retrieval of contact-handled TRU waste, remotely handled TRU waste, and defense high-level waste (DHLW); the investigation of interactive effects of heat- and radiation-generating waste packages with a salt repository; and the investigation of repository backfilling, plugging, and sealing. The program (see Table 3-2 and Figure 3-1) is scheduled to begin in 1983 and continue through the life of the facility. The test sequence begins with thermal-structural interactions to verify the ability of structural models to predict long-term repository response, and (assuming these results are positive) continues in stages to demonstration of DHLW retrieval from corroded and failed waste packages. Obviously, the earlier experiments are better defined than are the later experiments, which will allow for incorporation of the results from the early WIPP experiments and the on-going parallel experimental programs into the plans for the later WIPP experiments. This is appropriate since, although the general philosophy appears to be that the experiments are "verifications" of present concepts and models, it is almost inevitable that surprises will be encountered and that new concepts and models relating to waste forms, waste package materials, design, dimensions, and heat outputs will evolve over the next decade. To take maximum advantage of progress in waste disposal technology worldwide, the periodic revisions of the experimental program should be preceded by deliberate solicitation of ideas for experiments, instrumentation, and equipment from outside the DOE (cf. National Research Council 1979).

At present, WIPP is designed to accommodate a considerable variety of waste packages. While operational smoothness would benefit from fewer and better-characterized packages and waste forms, the experimental program should take advantage of the present lack of uniformity to make an operational input into the recommendations for size, shape, weight, and other criteria for the waste packages that will be used on a large scale.

The over-all facility design is as yet not fixed. A recent major revision has reduced facility cost substantially, at the expense of the rate of waste emplacement and of operational flexibility. The plant electrical system has lost some redundancy, which means that the electrical supply system for the experimental program cannot be relied on for those experiments and systems that demand an uninterrupted power supply (such as the brine migration experiments). The alternative facility orientation now being evaluated, which extends the storage area to the south of the present shafts instead of to the north, would isolate the experimental area (assuming it remains at its earlier-planned location north of the shaft) by 823 m (2,700 ft) from the storage area and from continuing construction and storage activities. This would benefit both the experimental and the storage activities in a number of ways, including reduced chance of interference and continued availability.

The WIPP FEIS and SAR (through Amendment 3) recognize that accidents associated with the experiments with DHLW constitute the largest risk of environmental contamination, of plant contamination, and of operator exposure. Complete procedures for carrying out these important experiments have not yet been written (nor is it reasonable to do so before more operational experience with less hazardous experiments has been gained). Previous hazard analyses contemplated no changes in the standard ventilation precautions, i.e., high efficiency particulate air (HEPA) filters normally off-line, and cut in on detection of radioactivity in the vent stream. However, special precautions, such as putting the HEPA filters in line in advance of the experiment, might be considered as part of the operational procedures for experiments involving the handling of degraded DHLW canisters. The special ventilation requirements of the room experiments on brine corrosion, if a significant H_2S content is introduced with the brine, also need to be developed.

The demonstration emplacement and retrieval activities will reveal any weaknesses (such as excessive time for operations) in the storage concepts (e.g., the side-wall emplacement of remotely handled TRU waste) or in the equipment procured to implement them, and should be given sufficient priority to allow alterations in advance of large-scale waste emplacement operations in the storage area. We may confidently expect remarkable progress in the next half-dozen years in such areas as automated sensing devices, robotics, remote imaging, and instrumentation and control for hostile environments. These developments should be continually screened for application to waste isolation by testing in the WIPP R&D program.

Accelerated tests, such as room closure measurements with a heat source four times reference design conditions, experiments with higher-than-expected radiation levels, and corrosion experiments on deliberately compromised canisters or overpacks, tackle the difficult problem of investigating long-term effects within the lifetime of one generation of experimenters. Overall, the approach is reasonable. Extrapolations from these experiments would be more convincing with practicable three-dimensional models and improved computer programs. One can reasonably expect to have these with the next generation or so of computers.

Since the number of experiments that can be undertaken in the WIPP project itself is finite, the number of variables that can be dealt with in the many combinations of waste package, overpack, backfill, and sleeve, or of plugs and seals, is limited. One could improve the usefulness of the WIPP tests by concentrating on the difference between in-situ tests and smaller scale laboratory experiments. Laboratory tests paralleling the WIPP tests would be helpful in validating the former, thus improving the eventual rate of development of new materials. In general, inaugurating the WIPP in-situ testing program does not decrease the importance of the laboratory and field research programs that have contributed so much to the choice of materials for the WIPP project.

CONCLUSIONS

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the WIPP program (pp. 32-34).

RECOMMENDATIONS

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU wastes at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU wastes (p. 32).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation. Outside developments in automated sensing, robotics, instrumentation in hostile environments, etc., should be systematically screened for application or testing at the WIPP facility (p. 33).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 33).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate the latter form of testing and thus permit expansion of the matrix by less expensive experiments (pp. 33, 34).

CHAPTER FOUR

WASTE ACCEPTANCE CRITERIA

The definitive statement of the TRU waste acceptance criteria for the WIPP project is contained in WIPP-DOE-069 (U.S. Department of Energy 1981). A summary of these criteria appears in Table 4-1.

The waste acceptance criteria are for the most part quite straightforward. They are concerned with establishing standards on dimensions, weight, radiation levels and the like, such that operational difficulties at the WIPP site will be minimized when waste emplacement actually begins. The criteria have a permissive flavor, which reflects the real-world consideration that existing stored wastes are very heterogeneous in terms of composition, physical state, and package configuration. Evidently, the philosophy has been adopted that inconveniences at the WIPP site are less consequential than those that would occur at the various storage sites if highly restrictive criteria were adopted. These inconveniences are acceptable on an interim basis, but it should be a stated objective of the lead management organization of the defense TRU waste program to work as rapidly as possible in the direction of standardized packaging of fully characterized and thoroughly stabilized waste.

The most debatable of the criteria are those related to the inclusion of organic materials in the waste. The presence of such material in sufficient quantity raises questions about combustibility in the short term and about gas generation, complexation, and possibly accelerated radionuclide transport in the long term.

FIRE

Fires underground, as is well known from coal mining experience, are particularly difficult to control. In practice it has proved to be very difficult to extinguish such fires because underground combustion sites are so well insulated thermally.

Fire prevention and control will, of course, be easier in a salt repository than in a coal mine. For fire safety to be fully credible, however, a waste disposal configuration should be stipulated that will self-extinguish without any fire control measures whatever.

A self-extinguishing configuration can be provided by stacking of the waste packages in such a way that combustible and noncombustible

TABLE 4-1 Waste-Acceptance Criteria for Contact-Handled and Remotely Handled TRU Waste

Criterion	Contact-handled TRU waste	Remotely handled TRU waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpack.	Same as for contact-handled TRU waste
Gas generation	Gas generation by all mechanisms must not exceed 10 moles/m^3 of disposal-room volume per year under repository conditions. In terms of waste composition, this criterion may be interpreted to mean that the average organic content of contact-handled TRU waste may not exceed 14 lb/ft^3 for waste in 55-gallon drums and 6 lb/ft^3 for waste in other containers.	No criterion; quantities are insignificant
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix; free liquids are not allowed.	Same as for contact-handled TRU waste
Explosives	Not allowed.	Same as for contact-handled TRU waste
Pyrophorics	Small quantities (up to 1% of the waste by weight) of radionuclide-metal pyrophorics may be accepted with other waste forms if they are dispersed throughout the waste.	Same as for contact-handled TRU waste
Toxic and corrosive materials	Toxic materials allowed only with special materials procedures and precautions; corrosive materials will not be accepted.	Same as for contact-handled TRU waste
Sludges and free liquids	Sludges and other waste forms containing readily desorbable water under repository conditions will not be accepted; free liquids will not be accepted.	Same as for contact-handled TRU waste
	CONTAINER	
Design life	10 years to allow retrievability.	Same as for contact-handled TRU waste
Structure	Type A requirements.	Same as for contact-handled TRU waste
	PACKAGE	
Structure	Type A; any damaged container must be overpacked.	Same as for contact-handled TRU waste
Handling	Devices to allow handling by a forklift.	Axial lifting pintle
Weight	Less than 25,000 pounds.	Less than 7000 pounds
Dimensions	Not larger than 8 by 12 by 8.5 feet.	24-inch diameter, 10-foot length
Surface-dose rate	Not exceeding 200 mrem/hr; containers with a surface-dose rate in excess of 10 mrem/hr must be color coded.	Less than 100 rem/hr
Surface contamination	5% of 49 CFR 173.397.	5% of 49 CFR 173.397
Criticality	30-gallon drum, 100 grams fissile; 55-gallon drum, 200 grams fissile; DOT-7A, 350 grams fissile or less than 5 grams in any cubic foot.	49 CFR 173, Subpart H; less than 5 grams in any cubic foot
Thermal power	Container must be color coded if the thermal power exceeds 0.1 W/ft^3.	Less than 500 watts per canister

SOURCE: U.S. Department of Energy (1981) materials are intermixed in a proportion such that the heat liberated by oxidation of the combustible component is dissipated. Thereby the temperature of the mixture is prevented from reaching the ignition point of the organic materials. A conservative a priori calculation of sufficient accuracy should be quite simple, given the data on maximum organic content of each package that is part of the waste certification documentation.

A self-extinguishing configuration does not, of course, eliminate the possibility of transient underground fires arising from transporter accidents, such as electrical faults and welding, that may involve one or more waste packages. The provision for handling such situations has not yet been specified (U.S. Department of Energy 1980-1982). This must not be overlooked in the Title II design.

GAS GENERATION

The gas-generation limit of 10 moles/m^3 of disposal-room volume per year (Table 4-1) is briefly explained in DOE-069 (U.S. Department of Energy 1981), with reference to supporting experimental data in SAND 79-1305 (Sandia National Laboratories 1979). The number was derived from a consequence analysis based on the effective permeability (taken as 0.1 microdarcy) of the geologic formation, with the condition that lithostatic pressure of 0.15 N/m^2 (150 bars) at the repository depth should not be exceeded.

From the gas-generation limit the permissible organic content of the waste was derived through the experimentally based conclusion that the major source of gas is the bacterial decomposition of the cellulosic component of the waste--primarily the plywood boxes. This conclusion is independent of whether aerobic or anaerobic conditions are assumed. Under the expected anaerobic conditions, methane is presumed to be the major constituent of the gas.

The limiting microbial gas-generation rates given in SAND 79-1305 are derived from experiments carried out under conditions that do not give adequate weight to certain fundamental facts of microbiology:

- Micro-organisms are critically sensitive to ambient humidity. Most species require a humidity of 90 percent or higher for growth, and there are no confirmed reports of growth at humidity below approximately 60 percent (Horowitz 1979).
- Metabolic activity is poisoned by the accumulation of metabolic products. This will limit the magnitude of the pressure generated by a gaseous metabolic product.
- Methanogenesis does not normally occur in the presence of sulfates. Hydrogen sulfide is a primary metabolic product in such systems. Sulfates are plentiful in the Salado Formation.

The likelihood of biological gas generation should be reexamined in the light of these generalizations, and others that may be discovered by study of the specialized literature on life in extreme environments.

The restriction imposed by humidity may be particularly significant. A saturated NaCl brine has a relative humidity of 70 to 75 percent at ordinary temperatures. If traces of calcium and/or magnesium chlorides are present in Salado salt, the humidity of a sealed repository could fall as low as 20 percent. Now that the SPDV program has made the Salado directly accessible, measurement of humidity should be made in a suitable still-air cavity.

The tendency for H_2S formation by sulfate-metabolizing bacteria suggests a possibility worthy of attention: that this gas, and the CO_2 likely to be a coproduct, might maintain the pH of a brine-inundated repository low enough (below 3-4) to cause corrosive dissolution of steel drums with generation of substantial amounts of gaseous hydrogen. The chemical part of this scenario is well known from oil field experience with "sour" gases under pressure (Shock 1953). The biological part, of course, depends on the ability of the organisms in question to thrive in the repository environment.

Radiolysis was also discussed as a source of gas generation. Because of the low level of total radioactivity in TRU waste, the rate of radiolytic gas generation estimated in the FEIS (U.S. Department of Energy 1980, p. 9-153) is negligibly small--only a small fraction of that assumed for microbial action.

The computational model used to calculate the repository pressurization associated with gas generation is straightforward. The conclusion that the repository pressure will be below the lithostatic pressure even for the bounding case is acceptable, especially in view of the fact that the source term used for the gas-generation rate is probably too high by orders of magnitude, as just discussed.

In view of the minor importance of gas generation for projected TRU waste, it is suggested that consideration be given to dropping the waste acceptance criterion relating to gas generation, particularly if the humidity in the repository proves to be less than 60 percent. However, the emplacement density of organic materials should be limited to conform with the self-extinguishment criterion stated above. Rough calculations indicate that the restriction on organic material imposed by the self-extinguishing requirement is easily met.

COMPLEXATION

Many documents, including the SAR (U.S. Department of Energy 1980-1982), examine the consequences of scenarios in which the Salado salt containment is breached. Radionuclides then move upward into the aquifers of the Rustler Formation and thence by hydrologic flow to the surface at Malaga Bend or elsewhere. Sorption by the clays and dolomites of the aquifers has been experimentally shown to be very strong for plutonium and its daughters, which leads to a significant retardation of the transport of these species with respect to the groundwater flow. Complexation by organic materials included with or derived from the organic component of the waste will interfere with the sorption process and shorten transport time accordingly.

A sensitivity analysis of the consequences of the reduction of K_d, the partition coefficient, by complexation is reported in SAND 79-1305 (Sandia National Laboratories 1979), and a similar analysis appears in EEG-8 (Wofsy 1980). Both analyses conclude that even complete elimination of the sorption effect would not increase the dose commitment to the maximally exposed individual to parity with the dose received from natural sources, owing to the long travel time for the water.

The FEIS does not even mention complexation as a factor in the establishment of waste acceptance criteria. Within the limits of the particular scenarios considered in the FEIS the omission probably is justifiable. In other possible scenarios, where flow occurs through fracture systems, or in the extreme case through karst, travel time would be reduced and sorption would become a matter for more careful evaluation, especially since in these two instances opportunity for sorption is materially reduced. The credibility of such scenarios needs further study (see also Chapter 6).

CERTIFICATION

The best possible set of waste-acceptance criteria is of doubtful effect unless compliance is systematically certified. Misgivings on this point have been expressed by the New Mexico Environmental Evaluation Group (EEG) and by this panel. Recent briefings and recently released documents (U.S. Department of Energy 1982; Whitty et al. 1982) are making it clearer how compliance can be assured.

A particularly important part of the certification strategy, and one that this panel supports, is the policy of beginning certification with newly generated waste. This postpones the serious problem of determining exactly what is contained within old packages that have inadequate documentation. Certification will not begin at any waste-generating site until appropriate procedures have been developed, facilities built, and personnel trained, all of which are easier with newly generated waste.

Less satisfactory is the proposed procedure for verifying compliance after the packages are received at the WIPP. The FEIS specifies only that each container be inspected for damage and contamination; then if the certification documents are in order, the container is ready for transportation underground. This panel would prefer to see a policy of having the WIPP equipped with state-of-the-art nondestructive examination devices, so that at least a sample from each shipment can be subjected to an independent verification.

After newly generated wastes have all been certified, it will be necessary to deal with stored wastes. Those of recent origin--since 1970, approximately--are stored retrievably and are comparatively well documented. Wastes in this category that are stored at Idaho National Engineering Laboratory (INEL) will be processed along with newly generated waste. Stored waste from other sites will be processed later, with technology developed at INEL in the Stored Waste Examination Pilot

Plant (SWEPP) and Processing Experimental Pilot Plant (PREPP) programs. Technology for preparation and transportation of remotely handled TRU waste is also to be developed in this second phase.

Another category is the special-case wastes, which include buried pre-1970 TRU wastes, uncertifiable stored wastes, contaminated soils, and the like. This panel endorses the proposed strategy of postponing decisions about these wastes until the other categories of wastes have been dealt with, additional technical or institutional developments have occurred, and more information has been obtained on costs and hazards.

These troublesome certification procedures could be simplified and transportation facilitated by shredding and pyrolyzing all the waste. Against this must be weighed the monetary costs and particularly the hazards to the operators of pyrolysis facilities. Evaluation of the factors on both sides of the option is highly subjective because practical experience is scanty. It is the judgment of this panel that the strategy proposed by Rockwell International (1982) is a reasonable compromise at the present state of knowledge. Further information on such issues as complexation might shift the balance to pyrolysis. That part of the waste which is readily certifiable is currently expected to be transported and emplaced without pyrolysis; that which is undocumented or for other reasons falls in the "special case" category is to be processed by whatever technology appears to be appropriate, including any of several varieties of pyrolysis. A substantial amount of practical information on pyrolytic processing is already available from experience with pilot facilities, and pilot testing of other techniques is already operating or in the planning stage.

In the view of this panel it is particularly important that the pyrolysis option or something functionally equivalent should be available. A certification procedure cannot be truly meaningful unless there exists a practical alternative for handling those wastes that fail to meet the criteria.

DEFENSE HIGH-LEVEL WASTE

The WIPP mission includes a program of experiments with retrievably emplaced, high-level waste, presumably solidified in glass and contained in metal canisters. No criteria have been written for this class of waste, even though the experimental area has been laid out and tentative plans for experiments have been formulated. It is important to have these criteria prepared well in advance of need.

CONCLUSIONS

- The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (pp. 35, 37).
- The criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into

account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity completely (pp. 37, 38).

o If there is biological activity, the presence of sulfate in the salt makes it likely that hydrogen sulfide, rather than methane, would be the major product (pp. 37, 38).

o From the WIPP viewpoint, the quality assurance system is inadequate, in that it requires no on-site verification of conformance of package contents to the certification (pp. 39, 40).

RECOMMENDATIONS

o As soon as feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 35).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (pp. 35, 37).

o The existing deficiency in the SAR on procedures for fighting transient underground fires should be remedied (p. 37).

o The humidity of still air in equilibrium with the salt and the pH of the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 38).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas-generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (p. 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (p. 38).

o State-of-the art equipment should be provided at the WIPP facility for nondestructive verification of compliance with those elements of the waste-acceptance criteria for which such equipment exists (p. 39).

o The existence of a practical alternative should be ensured for handling those TRU wastes that arrive at the WIPP site and that fail to meet the WIPP TRU waste-acceptance criteria. The alternative should be available at the time that it is needed (p. 40).

o Waste-acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The definition should be early enough to allow time for review before experimental operations begin (p. 40).

CHAPTER FIVE

DESIGN AND OPERATION OF FACILITIES

INTRODUCTION

Plans for the WIPP design, construction, and operation have changed continuously, and further changes can and should be expected. Flexible planning enables changes to be made to the design, construction, and operation of the proposed facility in the light of new information that emerges from the WIPP program and from other relevant programs. One important result of such changes has been to improve confidence in the predicted performance and safety of the facility. In this respect, it is particularly important that explicit arrangements be made to utilize the results from the SPDV experiments in the final design and performance assessment of the repository. Another important result has been to effect economies in the design of the proposed facility. However, great care must be taken to ensure that such economies do not impair the performance and safety of the facility.

SPDV EXPERIMENTS

The results of the SPDV experiments are regarded as crucial in establishing the performance and safety of the WIPP repository, and these results will provide a wealth of data concerning the behavior and properties of salt.

It is important that effective and timely comparisons be made between theoretical prediction of the SPDV experimental results and data obtained underground during these experiments. Such comparisons provide an essential mechanism for developing and helping to validate the theories upon which the design of the storage excavations are based. However, the extent to which the behavior and properties of the salt in the experimental area is similar to, or different from, the salt in the storage area must be taken into account in transferring knowledge gained in the former to design and prediction in the latter. Therefore, it is important that detailed observations of the properties of the salt be made and recorded during excavation of both the experimental and of the storage areas. Predictions of the results of the SPDV experiments will have to be made on the basis of theoretical calculations. Theory and calculational methods developed for the SPDV experiments and refined in the light of results from those experiments provide an important basis for the qualitative and quantitative evaluation of the design of the storage area. It is important that the design of the storage area reflect the knowledge gained as a result of the SPDV experiments.

The value of the SPDV experiments will be enhanced greatly by prompt publication of their results in scientific and technical journals, so as to facilitate their consideration by the scientific and engineering community, rather than only by those individuals involved directly with the WIPP project.

UNDERGROUND EXCAVATIONS

Once a suitable site for an underground nuclear waste repository has been selected, one of the most important factors--if not the most important one--contributing to the successful disposal of radioactive waste is the design of the excavations and associated facilities that constitute the repository. Mining engineering provides a wealth of experience related to the design and construction of a repository, but the function of a repository is very different from that of a mine. The principal objective in mining is to remove as much of the ore as is practicable, consistent with short-term safety. The principal objective in making repository excavations is to disturb the geologic media as little as is practicable, so as to ensure long-term safety and effective isolation of the wastes.

Adequate conceptual design of an underground repository requires recognition that the properties of a geologic medium, even salt, are unlikely to be uniformly satisfactory over the dimensions of the proposed repository site, and that many variations in the properties and structure of the salt at the depth of the repository will be revealed only as the excavations are made, and related underground experiments are done. Some of these variations may lead to unexpected difficulties in excavation or they may adversely affect the ability of the salt or the overlying strata to isolate the wastes from the biosphere. Accordingly, it may be desirable to treat some portions of the repository differently from others and perhaps even exclude some portions of the site from use for the waste disposal.

For these reasons, and to limit the extent of any accidents that may occur prior to final sealing of the repository, such as the intersection of a major brine reservoir or the outbreak of a fire, the repository should be laid out as a number of independent modules. Substantial barriers of undisturbed salt should be left between modules, to ensure that each module can be isolated effectively from every other module. No more accessways than are necessary for safe development of a module should penetrate these barriers, and each accessway should be provided with a bulkhead, which can be closed quickly at either end of the barrier. Ultimately, these accessways should be sealed permanently with a fill having low porosity and permeability. Devices for temporary closure of accessways, in the form of ventilation doors and other fabricated bulkheads, have been developed and are used extensively in the mining industry. In mining, permanent closure of accessways is usually effected by the construction of concrete plugs. For the WIPP site, a salt aggregate could be used. No details are given in the program documents available to the panel of either devices for temporary or permanent closure of accessways.

The current design (Figures 5-1, 5-2) comprises three shafts: (1) a construction, salt-handling, and intake-ventilation shaft; (2) a waste shaft; and (3) an exhaust shaft. An experimental area is laid out to the north of these shafts and the storage area is laid out to the south of them. Access from the shafts to the experimental and storage areas is by parallel entries, two to the experiments, and four to the storage area. The entries to the storage area (Figure 5-2) are separated from one another by pillars about 42 m (138.5 ft) thick and are penetrated by cross cuts at 61 m (200 ft)- and 91 m (300 ft)-intervals.

The storage area, measuring 629 m (2,064 ft) by 778 m (2,552 ft), comprises four panels on each side of the main entries. Within each panel are seven storage rooms, measuring about 10 m (33 ft) wide by 4 m (13 ft) high by 91 m (300 ft) long, with their long axes parallel to the main entries, and separated by salt pillars 30 m (100 ft) thick. The panels are separated from one another by barrier pillars 61 m (200 ft) thick. Access from the main entries to the panels is by cross cuts at intervals of about 91 m (300 ft) and 61 m (200 ft), the length of rooms and the thickness of the intervening barrier pillars, respectively. The overall extraction ratio is less than 25 percent, and the layout of the panels constitutes effective modularization, provided that the penetrations of the pillars can be closed effectively, both temporarily in an emergency and permanently after storage has been completed.

Using the SANCHO finite-element, large-strain creep code, Sandia has done a structural analysis of the original Title I design and compared this with two alternative layouts of the repository excavations (Krieg et al. 1979). In this analysis, a "standard structural model" for the geology was based on data from the ERDA-9 borehole (Wawersik 1979); mechanical properties for the salt were taken from SAND 79-1853 (Munson and Dawson 1979); and, for other rocks and seams, properties were taken from the literature or estimated. The analysis of the original design showed far-field effects that disturbed the superincumbent strata and were brought about by relatively small amounts of convergence across the excavations in the short term (10 years). These effects would increase continually with time, until ultimately the backfill becomes consolidated. Waste and backfill in these excavations are likely to have a void space of about 40 percent, unless special procedures are developed for greater compaction. In the longer term, this void space will allow much greater convergence across these excavations than that calculated in the analysis of the short term. Correspondingly greater far-field effects, particularly at stratigraphic discontinuities, may disrupt the salt in a very different way than would geologic events in the absence of man-made perturbations. Assumptions based on the behavior of salt in its pristine conditions may not be valid. Accordingly, analyses of the far-field effects should be done for much longer periods of time--say 50, 100, and 1,000 years--to show whether or not closure of the excavations will need to be limited. The amount of closure that would prevail if the cavities were filled with waste and

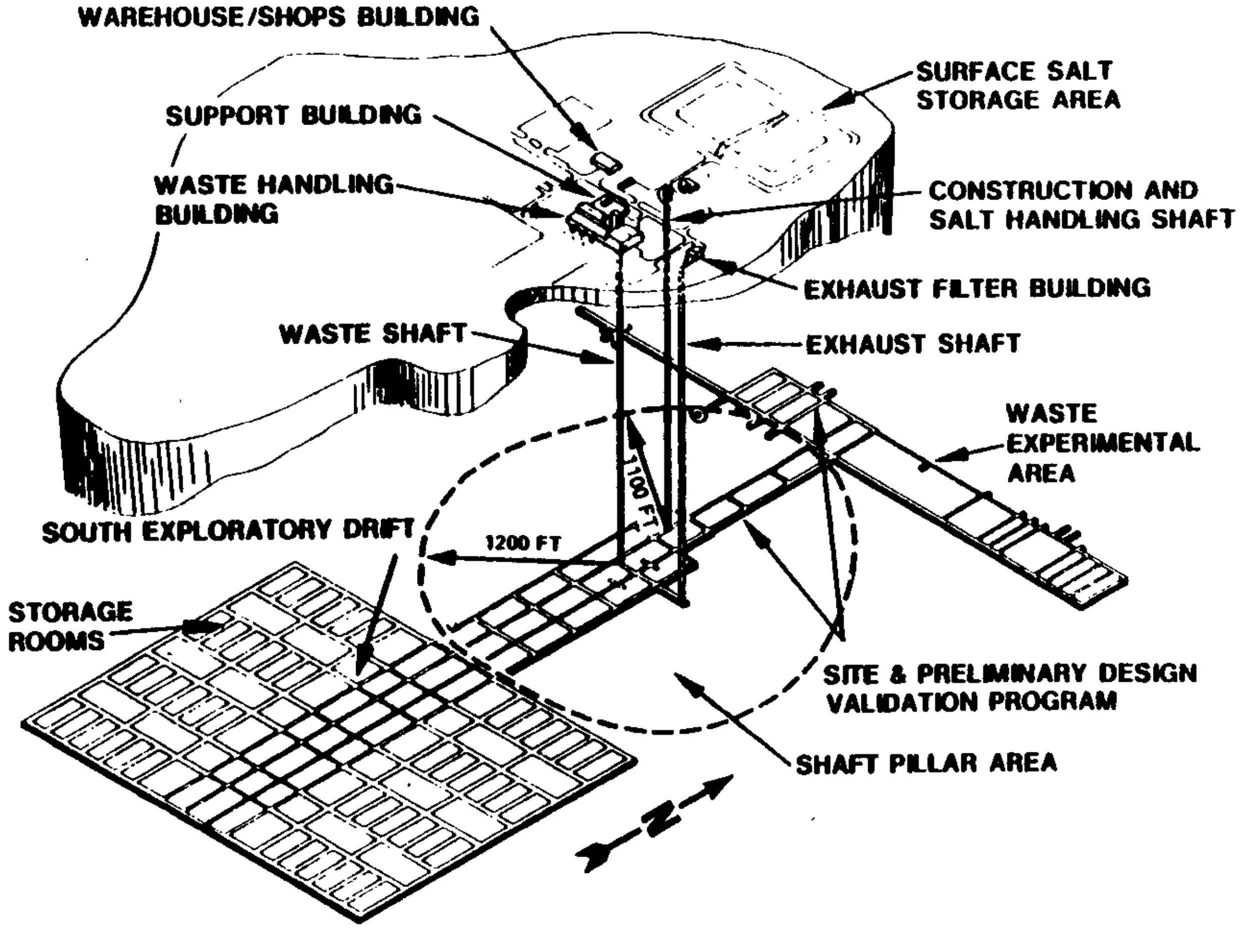


FIGURE 5-1 Cutaway diagram of the WIPP underground design. Source: Bechtel National, Inc. (1983).

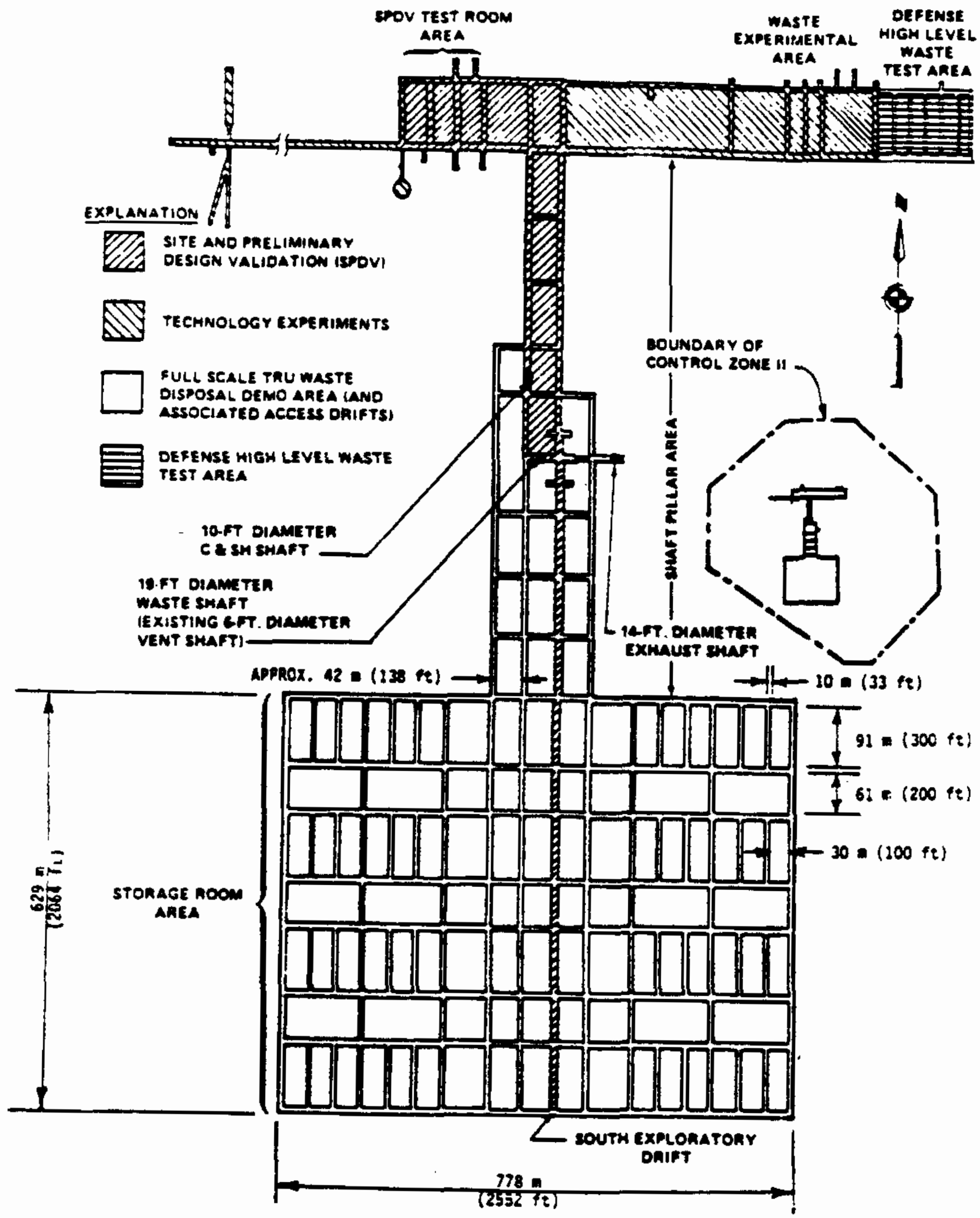


FIGURE 5-2 Representative WIPP underground layout. Source: Bechtel National, Inc. (1983).

backfill having an initial total void space of about 40 percent may be unacceptable. A finding that closure should be limited would have important implications for waste forms, backfills, excavation layout, and extraction ratio.

In the near field, the excavations of a repository make up a network of interconnected hydraulic conduits in the salt mass at the repository horizon. Closure of the excavations, even in the long term, say beyond 1,000 years, may not reduce the void space in the waste and backfill to a negligible value, so that the backfill may have a permeability much greater than that of the intact salt. This residual void space may result in a hydraulic conductivity through the repository excavations that is significantly greater than that of the pristine salt.

A careful analysis of the effects of void space on the hydraulic conductivity should be made, though the consequences would not be expected to be greater than those resulting from scenarios of water flow between two aquifers (Bingham and Barr 1979).

CHANGE FROM FOUR SHAFTS TO THREE SHAFTS

The recently proposed change (U.S. Department of Energy 1982) from a system of four shafts comprising:

- a waste-handling shaft;
- a construction, exhaust, and salt-handling shaft;
- a storage, exhaust shaft; and
- a ventilation, supply, and service shaft

to a system of three shafts comprising:

- a waste-handling and personnel shaft;
- a construction, salt-handling, and intake shaft; and
- an exhaust shaft

has profound effects for repository construction and operation.

The four-shaft system allowed for complete separation between construction and storage. Each of these two operations was planned to proceed concurrently and independently of the other, except for ventilation supply through a common shaft. This concept provided an exceptional degree of flexibility, redundancy, and safety.

The three-shaft system interlinks construction and storage operations in many ways. It involves cyclical and sequential operations on two shifts a day: One shift is for construction, the other is for storage. To operate on either shift in the three-shaft system, the ventilation subsystems in both the construction and storage areas must work. This requires that all three of the ventilation fans run on both shifts to provide about 83 m^3/sec (175,000 cfm) of air flow. In contrast, in the four-shaft system, the use of six fans was envisaged, only four of which were required at any time.

The principal ventilation load derives from the decision to use diesel trucks for underground transport. Ventilation requirements could be reduced if electric-shuttle cars and electric conveyors instead of diesel trucks, were used to transport salt underground. Diesel vehicles could still be used for the transport of men. If diesels were not used underground for the transport of salt, the ventilation requirements would be reduced to two fans, of which one would suffice in an emergency.

Electrical power to back up the 32 km (20-mile)-long high-voltage line from the substation to the WIPP site has been reduced to one manually operated 800-kw diesel generator, from two automatic 2,500-kw diesel generators sufficient to operate the man hoist and one fan. There are reported to have been two substation outages with duration longer than 8 hours over the past 5 years.

It should be noted that the proposed three-shaft system has redundancy more typical of that in conventional mining practice than of that in nuclear industry practice.

CONCLUSIONS

o The present plan to develop the storage areas to the south of the shafts and the experimental areas to the north of the shafts is commendable (p. 44).

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 44).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 44).

o Recently the repository design has changed from four to three shafts. The four-shaft system had a far greater degree of redundancy and flexibility, both in terms of the system and of operations, than does the three-shaft system (pp. 47, 48).

o The panel has not seen an adequate quantitative evaluation of the economic advantages of the three-shaft system that justifies forgoing the flexibility and safety of the four-shaft system (pp. 47, 48).

o The system as presently proposed with three shafts has redundancy more typical of conventional mining practice than of nuclear industry practice (p. 48).

RECOMMENDATIONS

o Explicit mechanisms for the transfer of information from SPVD experiments and information gathered during construction and development to final design must be established (p. 42).

o Displacements of the salt in the far field that occur as a result of long-term closure of excavations must be shown to be sufficiently small that they do not significantly increase the permeability of the bulk of the salt (pp. 44, 47).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 47).

- The justification for using diesel motive power for salt transport underground should be reexamined (pp. 47, 48).
- The effects of changes in the configuration of the surface facilities, the number of shafts, the ventilation system, and the electrical backup need to be further elaborated in terms of operational safety, efficiency, and nuclide releases (pp. 47, 48).

CHAPTER SIX

PERFORMANCE ASSESSMENT

This chapter is based primarily on the panel's review of the WIPP Final Environmental Impact Statement (FEIS) (U.S. Department of Energy 1980), the Safety Analysis Report (SAR) (U.S. Department of Energy 1980-1982) and Modeling Verification Studies: Long-Term Waste Isolation Assessment (D'Appolonia Consulting Engineers 1981). One of the main purposes of these documents was to estimate possible radiation exposure of both project employees and the general public. Such exposures could arise during preparation and loading of the wastes at the Idaho National Engineering Laboratory (INEL), transportation of the waste to the repository site, surface storage of waste at the WIPP site preparatory to emplacement, and as a result of accidents that may occur during operation of the facility. In addition, there may be releases of radioactive material to the environment if the repository is breached at some future time.

While the panel has reviewed the plans for packaging the wastes at INEL and transporting them to the WIPP site to determine how this affects the materials that will be emplaced in the repository, a detailed review of the consequences of routine and accidental events during these processes is beyond the scope of this study.

RELEASES AND OCCUPATIONAL DOSES DURING NORMAL OPERATION

Wastes delivered by either rail or truck to the WIPP site will be unloaded and passed through airlocks to the waste-handling building. The handling procedures are described in detail in the FEIS, and a number of conservative assumptions are made as to the levels of contamination. For example, it is assumed that all waste packages are contaminated to the maximum level of surface contamination permitted by National Regulatory Commission (NRC) and Department of Transportation (DOT) regulations. The total radioactivity that would be released to the environment from both surface and underground operations, from both residual surface contamination and leakage from damaged canisters of remotely handled waste, is estimated to be 0.004 Ci/yr. Throughout the analysis, the assumptions are conservative, so the final dose estimates are exaggerated.

The requirements of the FEIS for radiological impact analysis during normal operations could probably be discharged by simply noting that many years of experience with the handling of properly packaged wastes provide assurance that necessary calculations can easily be made.

The maximum annual occupational doses to workers at the WIPP facility from waste handling are estimated to reach an average of 0.8 rem for workers handling contact-handled waste and an average of 0.6 rem for workers with remotely handled waste. Although such doses, taken singly, are within acceptable limits, they may be too high for routine operations, since the same people may handle both types of waste, and other exposures from nonroutine events may occur.

The results of rather straightforward dose calculations, based on a conservative set of assumptions, show that for an individual at the closest point of habitation, the maximum dose (to the bone) is 0.007 percent of that received from natural radioactivity, and the whole-body dose would be less than 0.0002 percent of background (U.S. Department of Energy 1980, p. 9-30).

ACCIDENTAL RELEASES DURING OPERATION OF THE FACILITY

Accidents that may occur in the course of handling the radioactive wastes will have a potential for exposure to both the employees and nearby inhabitants. The consequences of a waste-handling accident are examined by analysis of 43 scenarios ranging from a vehicle collision in the receiving area (no radioactive material released) to various failures of the drums and canisters from collisions, drops down mine shafts, spontaneous combustion, and external fires. The radiation doses are calculated from estimates of the quantities of radioactivity released, the atmospheric concentration at a given location per unit of radioactivity released based on meteorological observations at the site, and measured population distributions.

The worst case for contact-handled TRU waste involves an underground fire, in which case the 50-year bone dose commitment off-site is estimated to be about 4×10^{-3} mrem. For remotely-handled waste, the worst case would be an accident in which a spent-fuel cask is dropped down the waste shaft, in which case the maximum dose commitment to a nearby inhabitant would be 2×10^{-3} mrem to the bone (U.S. Department of Energy 1980, p. 9-107). The maximum dose commitment to a worker from an accident would be 140 rem from an underground fire.

REPOSITORY BREACH SCENARIOS

For breach of the repository and effects upon the biosphere, there must be an event to breach the repository, a means to bring the wastes out of the repository, and finally a place for the wastes to move to at a lower fluid potential energy level than that of the repository. Without all three conditions, movement to the biosphere will not occur. In a number of the scenarios considered in the FEIS (U.S. Department of Energy 1980, p. 9-131 ff), not all of the above conditions are fulfilled.

Nevertheless, the calculations were carried out to determine the consequences of the implausible events. Finally, the studies were consequence analyses rather than risk analyses (i.e., the consequence of certain events are evaluated without regard to their likelihood). This methodology is particularly useful if the consequences are then found to be so small that the frequency of the event is not material. In all cases, the waste material is assumed to dissolve congruently with the salt, i.e., at the same rate as the salt.

The first scenario in the FEIS assumes a connection between the Rustler and Bell Canyon (of the Delaware Mountain Group) Formations through the repository with flow upwards and out of the Rustler into the Pecos River at Malaga Bend (see Figure 6-1). Though the flow may actually be in the opposite direction, this is a conservative assumption since the transmissivity and hydraulic conductivity of the Rustler are orders of magnitude greater than those properties in the Bell Canyon (i.e., greater flows and shorter residence times [U.S. Department of Energy 1980]). The Magenta and Culebra Members of the Rustler are treated as a single unit.

The second scenario assumes unsaturated flow through a drill pipe from the Rustler through the repository and saturated flow back to the Rustler and to Malaga Bend. The driving force for this scenario appears to be lacking, since the unsaturated water (8,000 ppm) flow does not appear to have the potential to push the saturated (400,000 ppm) flow out of the repository (see Figure 6-2).

The third scenario allows communication of the total waste storage horizon with the Rustler, but with no flow through the repository (i.e., the transfer is by diffusion only). Then, the flow is through the Rustler to Malaga Bend (see Figure 6-3).

The fourth scenario allows the total flow of the Rustler above the waste repository to flow through the repository and then back to the Rustler and out to the Pecos River at Malaga Bend (see Figure 6-4).

The fifth scenario deals with drilling into the waste repository and, in particular, with the dose to the drill crews. Bingham and Barr (1979) estimate the probabilities of breaching the repository salt formation by inadvertent drilling in the distant future.

A recent analysis (Woolfolk 1982) predicts the probability and consequence of a pressurized brine pocket below the repository with subsequent release to the ground surface (see Figure 6-5).

The consequences of drilling and using a water well near the site have also been evaluated (U.S. Department of Energy 1980-1982; Spiegler 1981).

Though it is not intended that solution mining will be carried out at the waste site, the consequences of doing so are more severe than the liquid breach scenarios but less severe than the drilling scenario considered in the FEIS and SAR as shown by the EEG report (Little 1982) for the maximally exposed individual. The population dose due to solution mining is much greater.

Some perspective on the total amount of radioactivity to be permanently isolated at the WIPP site might be gained by noting that the total inventory of the WIPP is expected to be 6×10^6 curies (Ci) (U.S. Department of Energy 1980-1982, Figure 8.1-4) and after 1,000

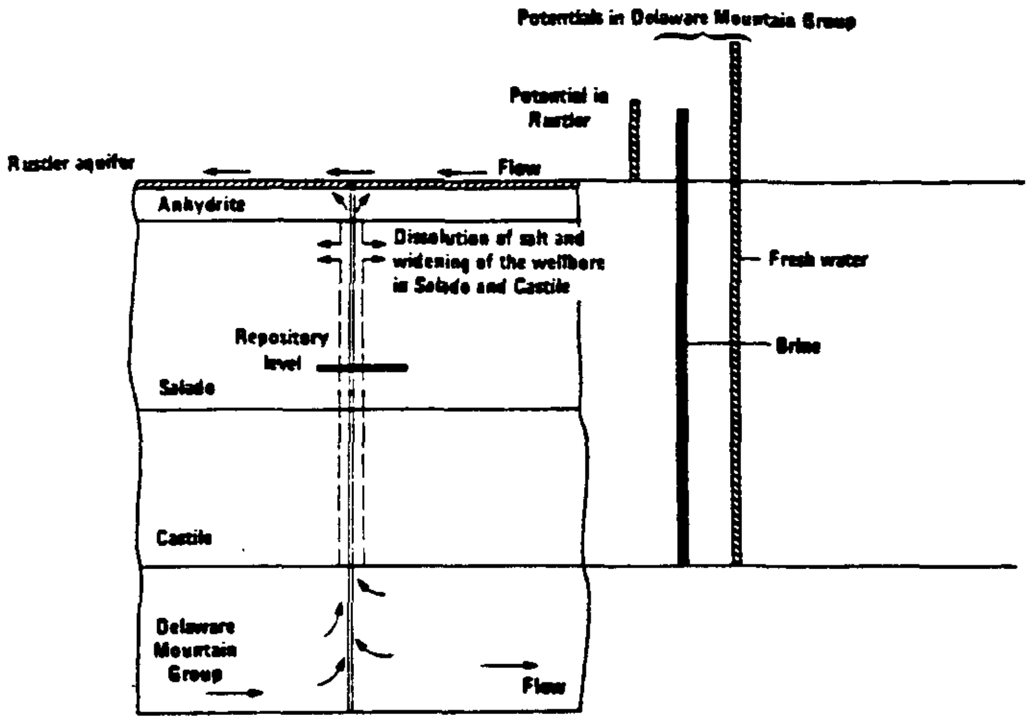


FIGURE 6-1 Schematic representation of scenario 1. Source: U.S. Department of Energy (1980).

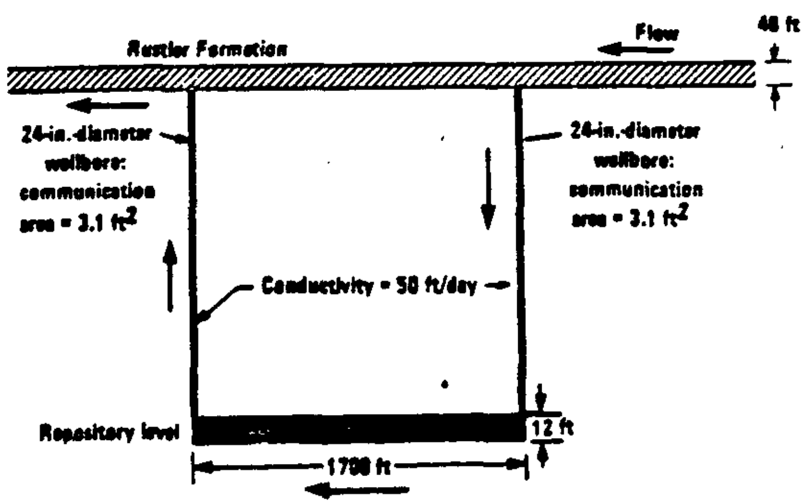


FIGURE 6-2 Schematic representation of scenario 2. Source: U.S. Department of Energy (1980).

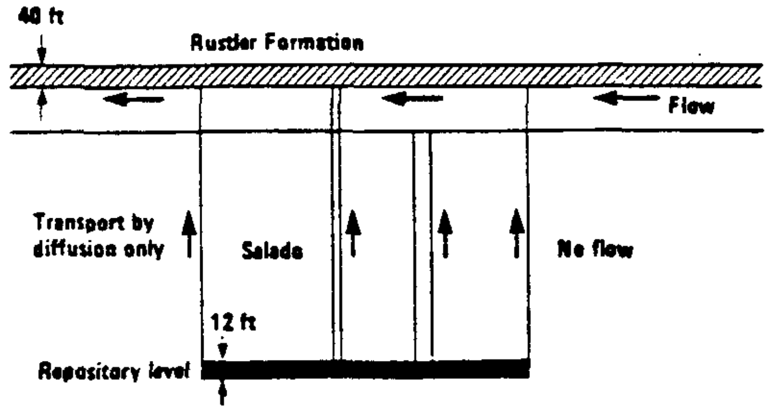


FIGURE 6-3 Schematic representation of scenario 2. Source: U.S. Department of Energy (1980).

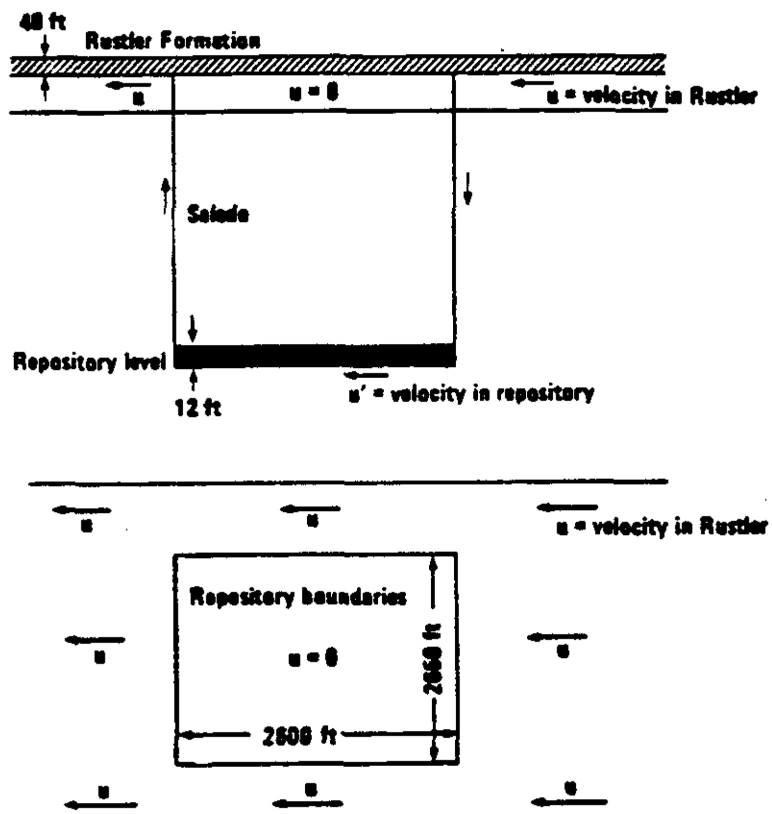


FIGURE 6-4 Schematic representation of scenario 4, showing the bounding condition (top) and velocities in the Rustler during the bounding condition (bottom). Source: U.S. Department of Energy (1980).

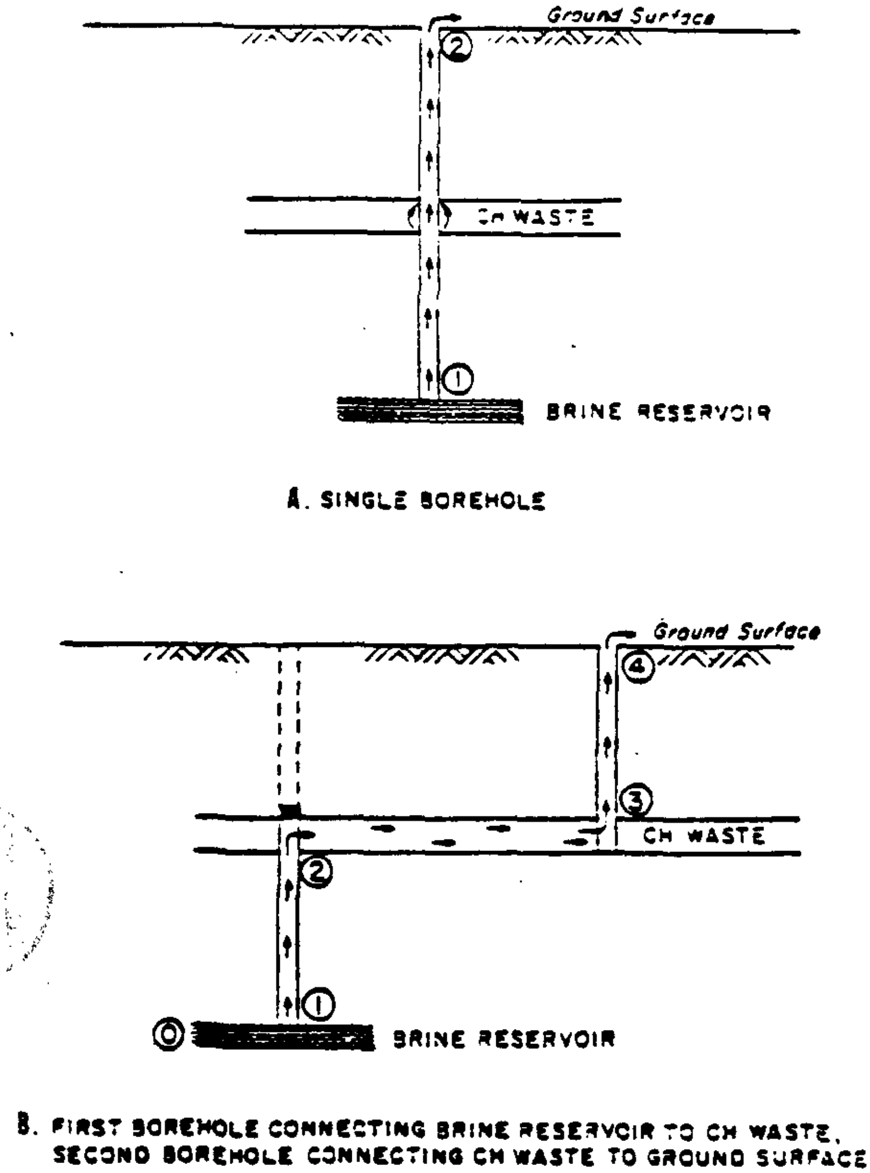


FIGURE 6-5 Schematic representation of scenario involving a brine reservoir below the repository and release to the ground surface. Source: Case et al. (1982).

years is still expected to be about 5 x 10^5 Ci (U.S. Department of Energy 1980-1982, Table 8.2-3). At the present time, the city of Albuquerque is expecting to use 15 x 10^6 Ci of cesium-137 for sterilization of sewage sludge.

Water flow times in the Rustler Formation from above the WIPP site to the Pecos River at Malaga Bend are calculated from models of flow through porous media to range from 5,000 to 100,000 years based upon point measurements. For the consequence analyses, the shorter flow times are used together with the shortest distance between the site and Malaga Bend. The actual flow paths may be substantially longer and particularly for the Culebra where there is some indication of an arcuate route to the Pecos. Substantially shorter flow times, 1,850 years, have also been postulated (D'Appolonia Consulting Engineers, Inc. 1981).

The sorption data listed in Appendix K-20 of the FEIS were derived from more than one source. It is not clear to what extent these data are applicable to the geochemistry of the Rustler Formation and to sorption from solutions containing appreciable concentrations of dissolved salt, nor whether precipitation may not be a more important mechanism than sorption. These uncertainties affect the estimated doses from radium-226. No discussion of the effects of such sorption uncertainties has been found in the report.

Using the porous-media analyses, the dissolution and transport processes take over 5,000 years for even the nonsorbing radionuclides and far longer for the sorbing species. Even considering wastes containing fission products, this gives ample time for strontium-90 and cesium-137 to decay without the additional delaying effect of sorption. Sorption by the dolomite delays the release of the transuranics, although some of their more toxic decay daughters, such as radium-226, contribute later to doses to man (U.S. Department of Energy 1980, p. 9-139).

The dosages (50-year commitment) to the maximally exposed individual (as well as the dose to the maximally exposed worker in the drilling scenario) from each of these scenarios, are given in Table 6-1. These doses were computed on the basis of International Commission on Radiological Protection (ICRP) reports ICRP-2 and ICRP-6. The revised permissible limits for neptunium-237 of ICRP-30 were not factored into these calculations. However, analysis of the dose calculations indicates that the portion of dose contributed by neptunium-237 is substantially less than one-two-hundredths of the total and, therefore, will have no effect on the dose numbers in Table 6-1.

The doses are calculated based upon very long transport times ranging from 1,200,000 to 1,400,000 years for the time for the peak concentrations to reach Malaga Bend (U.S. Department of Energy 1980, Table 9-60).

The scenarios selected in the FEIS would appear to be the bounding cases. Apart from the implausible mechanisms for water intruding into the repository and returning to the aquifer, the assumptions in each step of the analysis tend to exaggerate the dose estimates. For example, the waste is assumed to dissolve as rapidly as salt; no solubility limits for the waste material and for its radionuclides are

TABLE 6-1 Fifty-Year Dose Commitments for Maximally Exposed Individual from Bounding Scenarios of Breaches of the WIPP Repository (mrem)

Scenario	Whole Body	Lung	Bone
Bell Canyon to Rustler	7.7×10^{-3}	4.4×10^{-6}	1.3×10^{-2}
Restricted Rustler to Rustler Flow	1.7×10^{-3}	9.3×10^{-7}	2.8×10^{-3}
Diffusion Flow to the Rustler	7.0×10^{-5}	4.0×10^{-8}	1.2×10^{-4}
Unrestricted Rustler to Rustler Flow	1.5×10^{-2}	1.2×10^{-5}	2.6×10^{-2}
Drill into Repository	9.1×10^{-6}	1.7×10^{-5}	2.7×10^{-4}
Pressurized Brine Reservoir Flow to the Surface	7.3×10^{1}	3.2×10^{2}	1.5×10^{2}
Worker	1.7×10^{2}	6.6×10^{2}	------
Solution Mining of Halite	7.2×10^{1}	------	------
Natural Background	5×10^{3}	9×10^{3}	5×10^{3}

SOURCE: U.S. Department of Energy (1980, Tables 9-3, 9-64, 9-65, 9-66, 9-67); Little (1982, Table 4).

considered. Finally, no allowance is made for the fact that the radionuclides emerge into the Pecos River, the water of which is presently not potable because of high salinity. The water is not consumed by man or beast, and the river does not support a significant population of fish or shellfish. Even for these bounding cases, the dosages are so small that it is not worthwhile to consider more plausible cases. Confidence in the accuracy of these calculations of low dosages is strengthened by the independent calculations carried out by the EEG on transportation accidents, breccia pipe release mechanisms, withdrawal through wells, transport induced by pressurized brine reservoirs and long-term release scenarios. The dose commitments calculated by the EEG are similar to those shown in the FEIS, SAR, and brine reservoir report (Channell 1982).

Questions have been raised about the possibilities of reducing the time of travel of these higher-water-velocity flow paths by fractures or karst-type openings. Though recent publications (e.g., Gonzalez 1982) have dealt with the possibility of shortening the flow time by transport through fractures, rather than porous media, and thereby reducing the sorptive capacity of the Rustler Formation, no comprehensive analyses of the probability and consequences of fracture flow through the repository and Rustler to the Pecos have been made. This obviously needs to be done. Because it may be very difficult to prove that no connected fracture flow exists or is likely to exist, the problem might be finessed by computing the total water flow and flow rate through the aquifers above the WIPP site and, using the solubility limits of the individual nuclides, calculating the maximum amount of radioactive material that could be put into solution and transported to the Pecos.

CONCLUSIONS

- The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (pp. 50-51). (Since this analysis was completed, the lower limit of concentration for classifying transuranic wastes has been changed [9/30/82] by the Department of Energy from 10 to 100 nanocuries per gram. The amount of waste affected, the cost to handle it, and the safety consequences of this change have not yet been published).
- The long-term release scenarios, shown in Figures 6-1 to 6-6, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within prescribed limits (maximum 170 mrem whole body) and far below the dosages from normal background radiation (average 50 years, 5,000 mrem) (pp. 51-57).

RECOMMENDATIONS

o Hydrologic investigations and monitoring programs should be continued to more adequately resolve the differences between recent and initial interpretations of potentiometric maps and to provide a more consistent and confident definition of the rates and directions of groundwater flow within Rustler aquifers above and immediately adjacent to the site (pp. 56, 58).

o Though karst-type flow in the Rustler occurs near Nash Draw, the extent to which it reaches eastward is not clearly delineated. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be sharply reduced. Both the probability of such flows and their effect upon radiation dosages need to be determined (p. 58).

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APPENDIX A

LETTER REPORT, PARKER TO GLOYNA, May 1, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) [illegible]-6727

May 18, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
Department of Energy (MS B-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter report by the Panel on the Waste Isolation Pilot Plant (WIPP) on its review of the WIPP Draft Site Characterization Report (SAND 78-1596). The Committee on Radioactive Waste Management has discussed the substance of this letter and endorses the views of the Panel expressed therein.

I hope these observations will be useful in the continuing process of geotechnical characterization of the proposed WIPP site.

Sincerely,

Earnest F. Gloyna
Chairman

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 1, 1979

Dr. Earnest F. Gloyna, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dear Dr. Gloyna:

As part of its continuing responsibility to review criteria and guidelines for the location, design, construction, and operation of a proposed radioactive waste isolation pilot plant (WIPP), this Panel has reviewed the WIPP Draft Site Characterization Report (DSCR), SAND 78-1596, prepared by Sandia Laboratories for the Department of Energy. The DSCR, which has subsequently been published, with the same report number, as "Geological Characterization Report (WIPP)," is a compilation of the known geotechnical information about the proposed site and the surrounding region, with chapters devoted to regional geology, site geology, seismology, hydrology, geochemistry, resources, and special studies of WIPP repository rocks. It does not address such matters as socioeconomic considerations, accessibility, transportation and failure modes, which will need to be included in a complete site characterization.

The following brief account, which must be viewed in conjunction with the DSCR itself, is intended for a very limited audience of readers fully conversant with the contents of the basic document.

As a first step in this review, individual chapters of the DSCR were examined in detail by subgroups of the Panel with special expertise in the disciplinary areas involved, after which their separate comments were discussed by the full Panel in a meeting with the Sandia authors of the document.

The Panel then reviewed the extent to which the information contained in the DSCR provides sound geotechnical support for an environmental impact analysis and related decisions leading to the selection of an appropriate site for the proposed pilot plant. The review focused on the Report's exposition of geotechnical information with critical bearing on the site's probable ability to provide the desired long-term isolation of emplaced waste, e.g. seismic or tectonic uplift, intrusion of ground-water, thermal and mechanical characteristics of the host rock, and retardation effects along possible migration pathways. The Report did not treat, nor did the Panel consider, the effect of the emplacement of waste or the waste itself on the long term integrity of the repository. Although recognizing the considerable coverage and detail of the information presented, the Panel noted a few areas where additional data are desirable to more fully characterize the geotechnical aspects of the area under consideration. These include the following:

a) A major disagreement between conclusions reached in the DSCR and the views of R. Y. Anderson is mentioned in several places. Anderson, a professor of geology at the University of New Mexico at Albuquerque, who has specialized in the study of evaporite deposits in the Delaware Basin, was commissioned by Sandia Laboratories to prepare a report on the deep dissolution of salt in the region around the proposed WIPP site. Basing his argument on a postulated unconformity at the base of the Salado formation and on his hypothesis that the so-called "breccia pipes" are localized features of deep dissolution which originated as collapse chambers in salt beds immediately overlying the reef and basin aquifers, Anderson suggested that dissolution may be so rapid that the entire salt formation will disappear within a million years. The DSCR, on the other hand, considers only dissolution at the western edge of the salt beds and concludes that present rates will ensure preservation of the Salado at the WIPP site for at least a few million years. The Panel feels that a more thorough explanation should have been provided as to why the authors of the DSCR consider their views preferable to Anderson's hypothesis. On this same issue of salt dissolution, the DSCR estimates of the rate of retreat of the solution front two or three miles west of the site are evidently based on the assumption of uniform dissolution over a wide area under average conditions. A rational basis should be provided for this assumption, vis a vis the possibility of accelerated dissolution rates in local areas, with selective removal of salt from beneath the present sedimentary cover, particularly if pluvial conditions were to change in the future.

b) Additional data and analyses would be helpful to determine with greater confidence the current rates of tectonic uplift in the region and whether, as a result, the salt may be exposed to accelerated erosion at some time in the foreseeable future.

c) The so-called "breccia pipes" need more detailed analyses to determine whether they may serve as conduits for water that may have promoted, or may in the future promote, deep dissolution of the salt beds.

d) There appears to be sufficient information to resolve the question regarding the likelihood of upward flow from the Bell Canyon formation through the Salado, where the proposed repository horizons are located, to the overlying Rustler. This should be addressed.

e) Because rock properties have a strong influence on mine design, more detailed information is needed on the various rock types in the area and on their permeability, fracture, and thermal properties under conditions as similar as possible to those that would be found in a repository. Both laboratory and field tests approximating in-situ conditions will be required to develop this information.

f) The information on sorption of the important radionuclides by materials to be expected in possible migration paths, under conditions resembling those near a possible repository, seems to be sparse. As soon as the types of waste to be stored in the repository are known, a more complete discussion should be presented of the retardation anticipated in the migration paths.

g) The most recent episode of any recrystallization in the Salado formation near the proposed WIPP site is reported to have occurred about 200 million years ago. The Panel urges confirmation of this important date by further studies and other techniques, as described in Section 7.8 of the DSCR.

In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objectives, criteria for safe operation, and waste forms to be accommodated.

Sincerely,

Frank L. Parker

Frank L. Parker, Chairman
Panel on the Waste Isolation
Pilot Plant

APPENDIX B

LETTER REPORT, PARKER TO WILSON, SEPTEMBER 10, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue   Washington, D.C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT   (202) [illegible]-6727

September 12, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
U. S. Department of Energy (MSB-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter, by the Panel on the Waste Isolation Pilot Plant (WIPP), regarding the desirability of sinking an exploratory shaft at the proposed repository site. The Committee on Radioactive Waste Management has reviewed the letter and endorses the Panel's views expressed therein.

Sincerely,

E. Bright Wilson

E. Bright Wilson
Chairman
Committee on Radioactive
Waste Management

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT [illegible]

September 10, 1979

Dr. E. Bright Wilson, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Wilson:

During the past year, the Panel on the Waste Isolation Pilot Plant (WIPP) has become familiar with the findings of the various extensive geological explorations, including boreholes from the surface and attendant geotechnical studies, attempting to characterize the proposed WIPP site and provide a basis for judging this aspect of the site's suitability for a waste repository. This familiarization process has included briefings by representatives of Sandia Laboratories and the U. S. Geological Survey, study of both the published and unpublished technical literature, site visits, examination of actual borehole cores, and discussions with other experts in selected geotechnical areas.

Our efforts have brought to light no disqualifying results from these explorations and studies to rule out further consideration of the proposed site at this stage. The Panel has reached this conclusion after taking into account the comments made in my letter of May 1, 1979, reporting on our review of the WIPP Draft Site Characterization Report (issued as SAND78-1596, Geological Characterization Report), pointing out that certain effects have been observed which can be interpreted as indicating the possible existence of significant anomalies. Additional information is clearly required before these anomalies can be resolved

and a decision made regarding the adequacy of the proposed WIPP site for the construction of a repository. Furthermore, continued commitments to final details of repository design in the absence of additional site-specific information may be both misleading and wasteful.

The Panel is of the unanimous opinion that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and cannot resolve all the major remaining uncertainties. Accordingly, the Panel recommends that:

(1) An exploratory shaft be sunk at the site of one of the proposed access shafts as soon as practicable, to the depth of the proposed repository horizon.

(2) Drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

Development of the shaft, tunnels, and any other exploratory excavations should be consistent with applicable environmental and safety standards, strict quality assurance procedures, and should be compatible with an actual repository, if one is constructed at this site.

Sincerely,

Frank L. Parker

Frank L. Parker
Chairman, Panel on the
Waste Isolation Pilot Plant

APPENDIX C

CONTINUING EVALUATION OF THE CARLSBAD SITE, July 28, 1980

REPORT NO. DOE/CH/93023-1

Report No. DOE/CH/93023-1

CONTINUING EVALUATION OF THE CARLSBAD SITE

A Report to the U. S. Department of Energy, prepared by the Panel on the Waste Isolation Pilot Plant of the Committee on Radioactive Waste Management.

COMMISSION ON NATURAL RESOURCES
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
July 28, 1980

N O T I C E

ABSTRACT

It is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements, set forth in his February 12, 1980, message to the Congress, for evaluation of this site as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

NOTICE: The project that is the subject of this report was authorized by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Such authorization reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

The report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee of the National Academy of Sciences.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

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NOTE: Two Panel members did not participate in the deliberations leading to this report; John W. Winchester was out of the country on sabbatical leave, and Karl P. Cohen is a new member of the Panel.

CONTINUING EVALUATION

OF THE CARLSBAD SITE

The Panel on the Waste Isolation Pilot Plant (WIPP) was organized by the National Academy of Sciences in 1978, under the Committee on Radioactive Waste Management of the National Research Council, to review the scientific and technical criteria and guidelines for designing, constructing, and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere, with specific attention to a proposed site near Carlsbad, New Mexico.

On February 12, 1980, President Carter transmitted to the Congress "A Report on His Proposals for a Comprehensive Radioactive Waste Management Program." This report states the President's decision that the WIPP project, currently authorized for the unlicensed disposal of defense transuranic waste and for research and development using high-level defense waste, should be cancelled; but that the Carlsbad site will continue to be evaluated, along with other sites in other locations, for possible use as a licensed repository for defense and commercial high-level wastes.

The Panel has reviewed in depth the work of the DOE contractors on the geologic characteristics of the Carlsbad site, the characteristics of the defense and spent-fuel radioactive wastes that have been considered for emplacement, and the conceptual design of the repository. The WIPP Draft Environmental Impact Statement has been analyzed with

respect to the potential impact on public health and safety.

As a result of these deliberations, the Panel has previously concluded that continued investigation of the Carlsbad site is warranted and has recommended that the project proceed with an exploratory shaft to determine in greater detail the geologic, hydrologic, and structural features of the candidate salt beds, and with in-situ tests as necessary to evaluate the geotechnic adequacy of this site for a waste repository. The Panel considers these in-situ tests to be no less timely and technically desirable within the framework of the President's statement.

In connection with the Carlsbad site, a talented team of scientists and engineers has been assembled, and extensive geological exploration has been conducted. Laboratory facilities are excellent, important experiments on waste disposal are under way, and underground engineering designs have been developed. The project has gained momentum that would be difficult to recapture if it were to be interrupted. There are sound technical reasons for continuing the exploratory work:

1. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

   The analyses made thus far, supported by ongoing and planned testing programs to validate these analyses,

lead to the reasonable expectation that the site may be suitable not only for its original limited purpose as a defense transuranic waste repository but also as a licensed repository for both defense and commercial high-level and transuranic waste. The present experimental program will yield results that can be applied to the expanded purpose envisioned in the President's program. The exploratory shaft, now planned and ready to be constructed to a depth suitable for transuranic waste, can be extended to a lower horizon, where there is another salt bed that may be better suited for high-level wastes. The information obtained from this exploratory work will not only be useful for further evaluation of the Carlsbad site but can also be applied to other candidate salt formations.

2. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives.

Very long lead times are involved in the President's proposed new program of selecting alternative sites, constructing test facilities at each, choosing a first repository site, and eventually constructing one or more licensed repositories.

The extensive information already obtained on the Carlsbad site and the demonstrated expertise of the existing investigative teams provide an

opportunity to proceed much sooner with in-situ testing at a potential candidate site--a capability which will have to be developed before this or any other site can be selected for a first actual repository.

More is known about the Carlsbad site than about any of the other sites under consideration. Questions remain that will require resolution by additional analyses and testing, but such questions are normal for this stage of an investigation.

The Panel concludes that it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:

- providing prototype experience in site qualification;
- testing, in situ, performance assumptions about the geologic medium; and
- developing techniques and information which will be required in the licensing process.

If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review.

APPENDIX D

NATURAL RESOURCES AT WIPP

OCCURRENCE OF POTASH AND HYDROCARBONS

The originally proposed controlled-access area at the WIPP site, including Zones I, II, III, and IV, has recently been reduced by the proposed elimination of Zone IV. The area of Zone III has been slightly increased to give a square area comprising 16 sections, as shown in Figure D-1. This means that most of Zone IV is now open for exploitation of its mineral resources. The consequences to repository integrity of the contraction of the controlled-access zone are discussed below.

The resources currently considered within the original area include caliche, gypsum, salt, sylvite, langbeinite, crude oil, natural gas, and distillate. Of these, the potash minerals and hydrocarbons (Table D-1) are generally considered to be the most significant (Brausch et al. 1982). The deposits of caliche, gypsum, and salt are not considered economic reserves (defined as resources that can be extracted profitably by existing techniques and under present economic conditions).

Hydrocarbons

The new proposal is that within the time limits of repository control, no drilling will be allowed within Zones I, II, and III. Since the hydrocarbon horizons are below the salt sequences, directional drilling from Zone IV could be considered to explore for hydrocarbons. The exploration for and possible removal of hydrocarbons could be accomplished without penetrating the repository. However, the panel believes that DOE should have the authority to review and approve each proposed drilling and recovery project in Zone IV in order to assure procedures consistent with repository integrity.

Potash

The Carlsbad region has been the principal source of potash in the United States for many years. The established mines are located to the north and west of the WIPP site. These potash zones are also known to

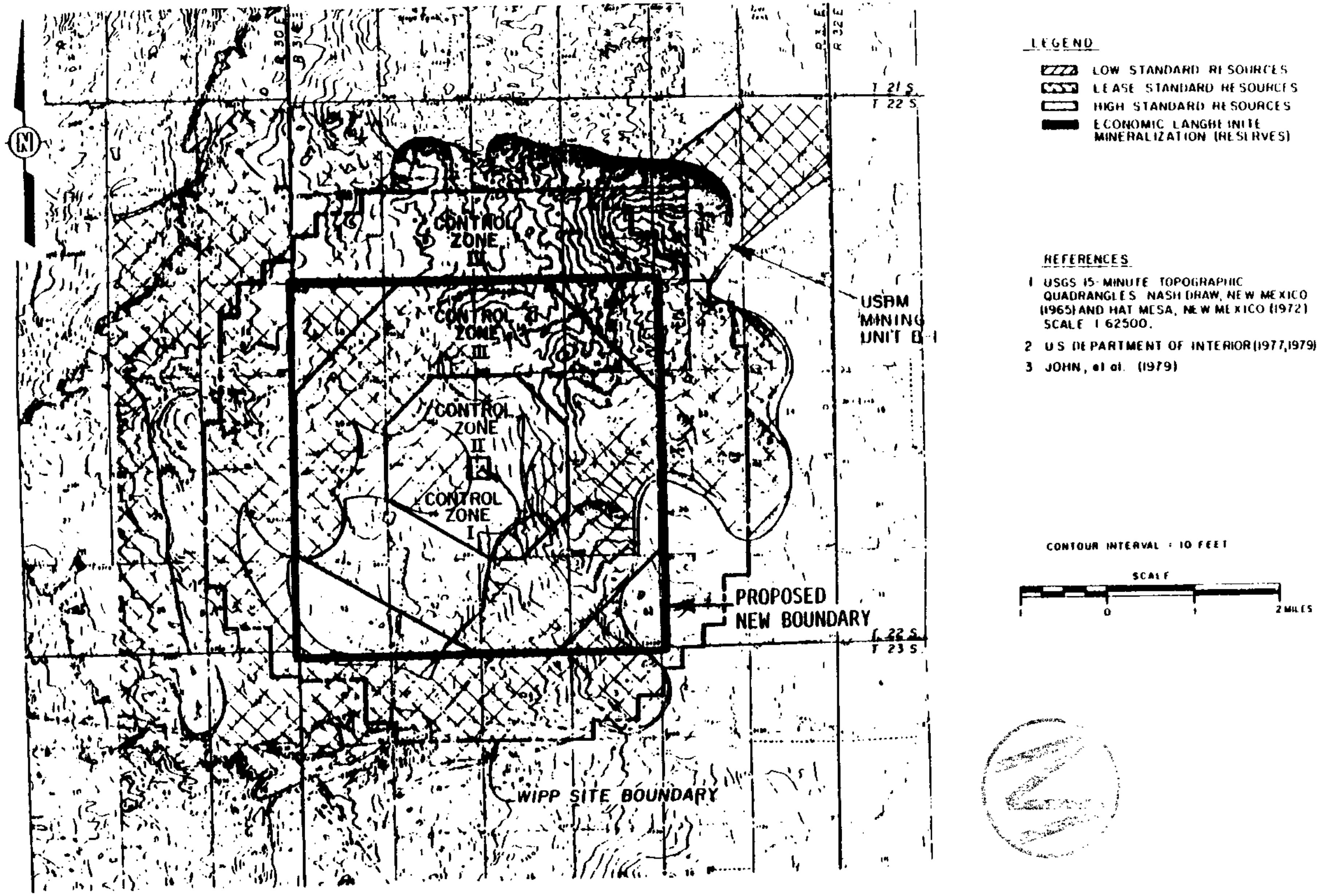

FIGURE D-1 Proposed new control zone boundary and potash deposits at the WIPP site. Source: Brausch et al. (1982).

TABLE D-1 Significance of the Resources and Reserves at the WIPP Reference Site

Deposit	Reference Site	Region	United States	World
		RESOURCES[a]		
Sylvite				
Quantity, million tons K_2O	10.44	500	1,000	100,000
Percentage at reference site		2.1	1.0	0.0104
Langbeinite				
Quantity, million tons K_2O	16.15	No estimate available		
Crude Oil				
Quantity, million barrles	37.50	1,915	200,000	Not Available
Percentage at reference site		2.0	0.019	
Natural Gas				
Quantity, billion cubic feet	490	25,013	855,000	Not Available
Percentage at reference site		2.0	0.057	
Distillate				
Quantity, million barrels	5.72	293	Not Available	
Percentage at reference site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	3.66	106	206	11,206
Percentage at reference site		3.4	1.8	0.033
Langbeinite				
Quantity, million tons K_2O	4.41	38[d]	38[d]	Not Available
Percentage at reference site		11.6	11.6	
Crude Oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at reference site		0	0	0
Natural Gas				
Quantity, billion cubic feet	35.35	3,853	208,900	2,520,000
Percentage at reference site		0.95	0.018	0.0015
Distillate				
Quantity, million barrels	0.55	169.1	35,800	Not Available
Percentage at reference site		0.32	0.0014	

[a]Data Sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.

[b]Data Sources: Hydrocarbons, Keesey (1976) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM, 1977).

[c]The U.S. Bureau of Mines (USBM, 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.

[d]Not an official estimate by the U.S. Geological Survey; see Section 9.1.4.

SOURCE: U.S. Department of Energy (1979).

be present east of the WIPP site, becoming deeper toward the east. The extent of the potash beds throughout the basin has not been thoroughly investigated, but fragmentary data from oil well logs indicate these beds are not of high grade in potash content or thickness. The potash ore horizons at the WIPP site are from 457 m (1,500 ft) to 549 m (1,800 ft) below the surface and, in general, are insufficient in either grade or thickness to make the mining economically attractive at the present time. The mineral langbeinite [$K_2Mg_2(SO_4)_3$] may have some economic value as it has a special application in fertilizer for the types of plants that are sensitive to chloride ions. Within the new limits of Zone III, the reserves of langbeinite are estimated to be about 12 million metric tons (13.3 million tons), and sylvite is not present. The areal extents of sylvite and langbeinite ore in the new and revised Control Zones are shown in Figure D-1.

Questions regarding the classification of these potash deposits as reserves or resources and the timing of future development are complex. The discovery of potash deposits in the Michigan Basin, which are of significant quantity and quality, could affect the value and, therefore, the classification of the Carlsbad deposits (Mathews 1970). The Michigan deposits are some 3,130 m (7,000 ft) to 3,440 m (8,000 ft) deep, and their economic recovery has yet to be determined; however, the geographical location with relation to the fertilizer market, water availability, land availability, and other such factors, favor their value and might depress the value of the potash deposits in the Carlsbad region. The extraction of potash in Zone IV is not presently economic.

CONSEQUENCES OF NATURAL RESOURCE EXTRACTION ON CONTROL ZONE IV

Consideration of the possibility of permitting mineral exploration and extraction on Control Zone IV has been justified as a balancing of the fact that "the primary concern of the DOE is protecting the public health and safety" against the recognition that, in addition to such concern, "the state of New Mexico . . . does rely upon the royalties generated from resource recovery as a significant source of revenue" (Brausch et al. 1982). Zones III and IV each provide a 1-mile buffer around the repository excavations under Zone II. Zone II is defined as the "area of approximately 1,800 acres which overlies the area of maximum potential underground development." The depth of the repository has been set at a depth of approximately 655 m (2,150 ft). The resources of concern are principally the potash salts which are located 61 m (200 ft) to 122 m (400 ft) above the repository depth, and potential hydrocarbon resources which are well below the repository depth. The other resources, such as salt, gypsum, and caliche, were considered of insufficient importance to warrant concern, as their abundance throughout the area is such that the withdrawal of this area would have no impact on their availability.

Subsidence

The effects that may be anticipated on the extraction of resources by excavating the repository cavity are principally those related to the redistribution of rock forces. Thus, the questions to be addressed are: (1) How will the location and construction of the repository affect the removal of potash beyond the control zones? and (2) Will the possible exploration for and removal of hydrocarbons endanger the repository? These questions are all concerned with predicting the effects of subsidence. The potash deposits are above the cavity, and the hydrocarbon removal would be related to the subsidence below the repository.

Subsidence at the surface or at points below cannot exceed the height of the entry. The distance of the subsidence is related to the extent of extraction and other factors unique to the overlying strata. Thus, with a 3-m (10 ft)-high entry and 25 percent extraction, the maximum subsidence above the cavity would be 0.76 m (2.5 ft). Since the salt will flow plastically and the rooms and entries are to be backfilled, this would decrease the subsidence at least by 50 percent or 0.38 m (1.25 ft). In addition, because there are 610 m (2,000 ft) of overburden, the bulking factor would be sufficient to make this subsidence over the entry even less. These are reasonable assumptions in agreement with mining practice (Society of Mining Engineers 1973) The extent of the effects of subsidence are discussed at some length in the Natural Resources Study report by Brausch et al. (1982). Using unconsolidated sand as a model, the angle of draw would be 45°C. Thus, for an excavation at a depth of 610 m (2,000 ft), the area that could be disturbed at the surface would extend 610 m (2,000 ft) beyond the excavation perimeter. If the horizon from which resources are to be mined is 61 m (200 ft) above the repository horizon, the limit of the zone of influence of the repository would be 61 m (200 ft) beyond the excavated edge of the repository. The angle of draw for salt is quoted at various values. The study report states that for New Mexico potash mines, the angle of draw is typically considered to be 45°C.

The nature of subsidence effects from hydrocarbons extraction is significantly different from mined extraction. Since the hydrocarbon horizons are well below the repository and there is a considerable thickness of salt in the Salado and Castile formations, there is no evidence that there would be a measurable subsidence effect by their withdrawal.

Potash Operations

Developing potash reserves involves three sequential steps: (1) exploration, (2) mining, and (3) ore processing. The exploration step requires the drilling of boreholes completely through the potash zone and something less than 6 m (20 ft) beyond to establish mine floor conditions. Since the depth and lateral control of such boreholes is between 1.5 (5 ft) and 3 m (10 ft), and the depth of the potash zone is some 61 m (200 ft) to 122 m (400 ft) above the repository, there is little chance of any detectable influence from the repository particularly if the mining and prospecting are not permitted in Zone III, which extends one mile beyond the repository limit.

Potash mining is done by shaft sinking and room and pillar development. If water zones are encountered they are sealed by grouting. The New Mexico mines are typically free from water intrusion and the occasional incidence seems to come from pockets of limited volume. Several approaches have been made to evaluate the limiting distance of influence from the repository toward the nearest possible mine. It should be pointed out that this distance is between the outermost repository excavations at 655 m (2,150 ft) and the nearest potash excavation at the potash zone level, e.g. 61 m (200 ft) to 122 m (400 ft) above the repository entry. Using the empirical 45^{o} angle of draw and a difference in depth of 61 m (200 ft), there is no effect beyond 61 m (200 ft) from the repository, and at a 122 m (400 ft) difference, the limit is 122 m (400 ft) from the repository, etc. Brausch et al. (1982) present several more sophisticated analysis methods, with the conclusion that the effects of the WIPP facility would extend a maximum distance of 115 m (376 ft). They conclude that a potash zone 610 m (2,000 ft) deep and a repository 655 m (2,150 ft) deep would show no interaction if separated by 213 m (700 ft) or more. On the surface above the site the repository could have an influence to 655 m (2,150 ft) beyond the boundary between Zone II and Zone III, and the influence of a potash mine at a depth of 610 m (2,000 ft) in Zone IV could extend inward 610 m (2,000 ft) from the Zone III-Zone IV boundary. This would leave some 305 m (1,000 ft) of surface undisturbed. Nearer the repository horizon, the distance would be proportionally greater.

Stress-induced increases in hydraulic conductivity were examined (Brausch et al. 1982) for the inert gases and several hydrocarbons. It was concluded that while the mining of potash "would result in a zone immediately surrounding the openings in which the hydraulic conductivity of the rock would be greatly increased," further from the mine, the hydraulic conductivity would be less and "therefore no preferential paths for groundwater flow between a potash mine developed within Control Zone IV and the WIPP facility would be expected to be created due to stress induced change in hydraulic conductivity."

Hydrocarbon Exploration and Production

The hydrocarbon development in the vicinity of the WIPP site requires drilling and removal of its hydrocarbon values. Since the target reservoirs are considerably below the repository, deviated drill holes are applicable. Standard well techniques of casing, cementing, and production can assure that minimal damage to the rock system will take place. Recovery and stimulation methods, e.g., acidizing and hydraulic fracturing are all at sufficient depth and under sufficient control to have no effect on the integrity of the repository (Brausch et al. 1982).

Solution Mining

The technique of solution mining has generally been excluded as a mining method to be considered. The technique has, however, been suggested as a means of making storage cavities for hydrocarbons. While this mining system requires water to dissolve the salt, the stresses and water convection problems do not differ from standard mining when the shape and size of the cavities are taken under consideration. It is possible that Zone IV could be considered for storage sites. It is quite obvious, however, that there is no apparent reason to locate a storage cavern in any of these Zones as any location with 244 m (800 ft) of overburden and a minimum of 9 m (30 ft) thickness of salt will be sufficient to make a suitable storage cavity. Thus, while there is little technical reason for prohibiting storage cavities to be constructed within Zone IV, there is no obvious advantage in doing so. Solution cavities should be restricted from Zone II and III.

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APPENDIX E

BRECCIA PIPES

Of the various karst landforms and deposits observed in the Delaware Basin, only three have been shown to be breccia pipes, despite the many miles of geophysical surveys (Figure E-1), the drilling of 71 shallow and deep exploration holes in the vicinity of the WIPP site, examination of 300 oil and gas well records adjacent to the WIPP site, the detailed mapping of subsurface and surficial deposits, and the extensive mining of McNutt potash on three sides of the WIPP site. By 1976, 142 km^2 (55 sq miles) of potash mines were developed in the region above backreef, reef, and forereef deposits in the Delaware Basin. Despite these extensive excavations, only one breccia pipe was encountered, Hill C (Figure E-2). Another possible pipe other than Hills A and C was reported to have been penetrated by one of more than 300 potash exploration holes drilled in the region. No conclusion can be drawn from this report because data were scanty.

These observations indicate that breccia pipes are exceptions, rather than the rule, in the Delaware Basin, and are far more restricted in their distribution than originally implied by Anderson. Anderson and Kirkland's model (1980) for pipe formation requires the concentrated solution removal of salt at depth (they postulated the Bell Canyon Aquifer), presence of unsaturated groundwater at some time in the history of the pipe, an aquifer or aquifers with sufficient hydraulic conductivities and porosities to allow groundwater to transport salt from the aquifer, sufficient gradients to induce groundwater flow, and an outlet or sink for both the water and dissolved salt. The bounding calculations of Wood et al. (1982) for necessary rates of groundwater circulation and salt dissolution show that necessary and sufficient conditions for breccia pipe development in the number, size, and time frame required to threaten the integrity of a WIPP repository cannot be met within the Bell Canyon Aquifer. This is in agreement with Lambert's (1982) geochemical and isotopic data.

Conditions could be met for breccia pipe formation only within the Capitan Reef of the Delaware Basin and near its forereef and backreef environment. An abrupt collapse of Salado and Rustler roof rock into a large void temporarily supported by an anhydrite "beam" within salt (Snyder and Gard 1982) or related resistant layer within salt could account for breccia pipe characteristics observed as well as the large diameter and large volume of rock instantaneously displaced into Kermit

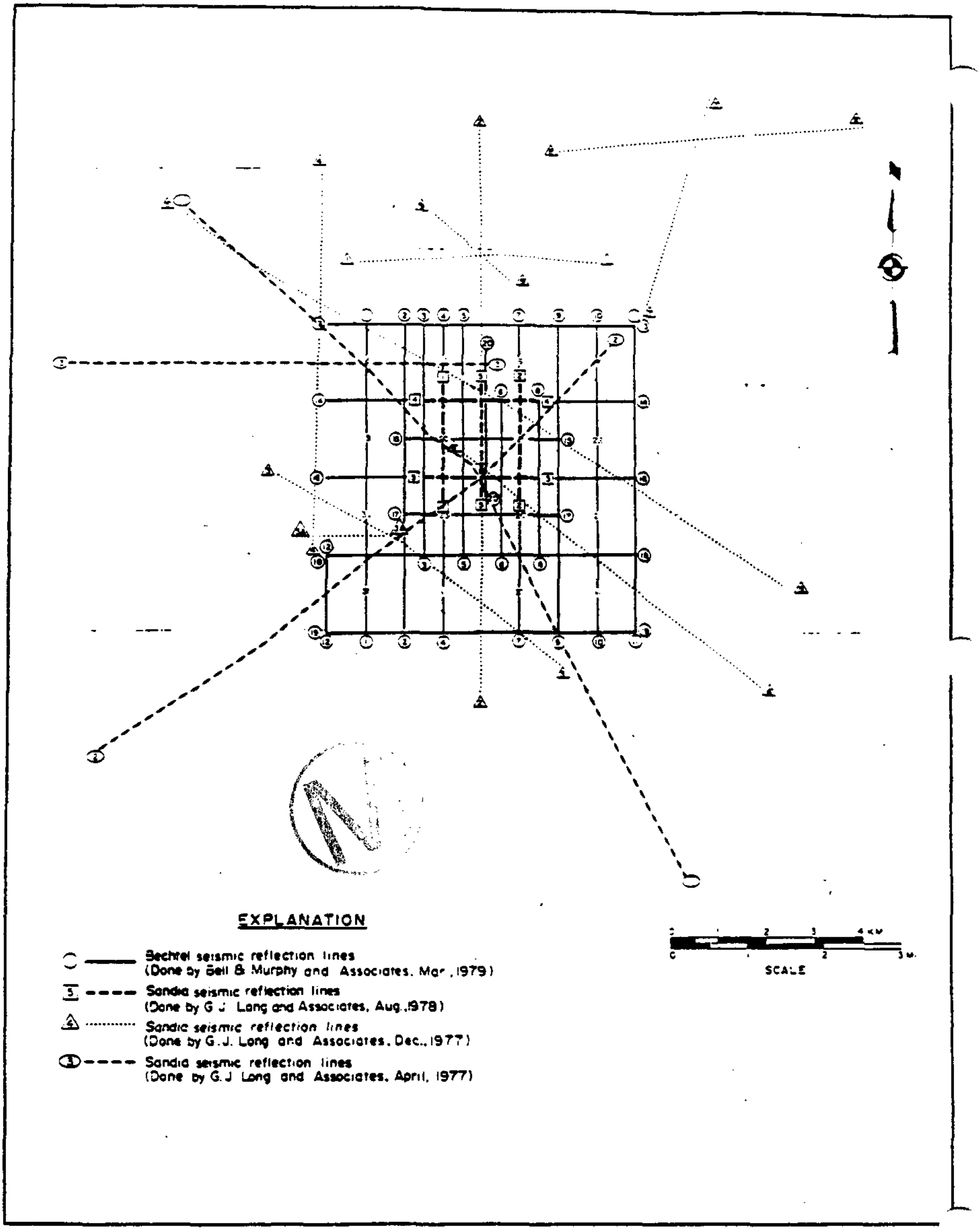

FIGURE E-1 Seismic reflection lines. Source: U.S. Department of Energy (1980-1982).

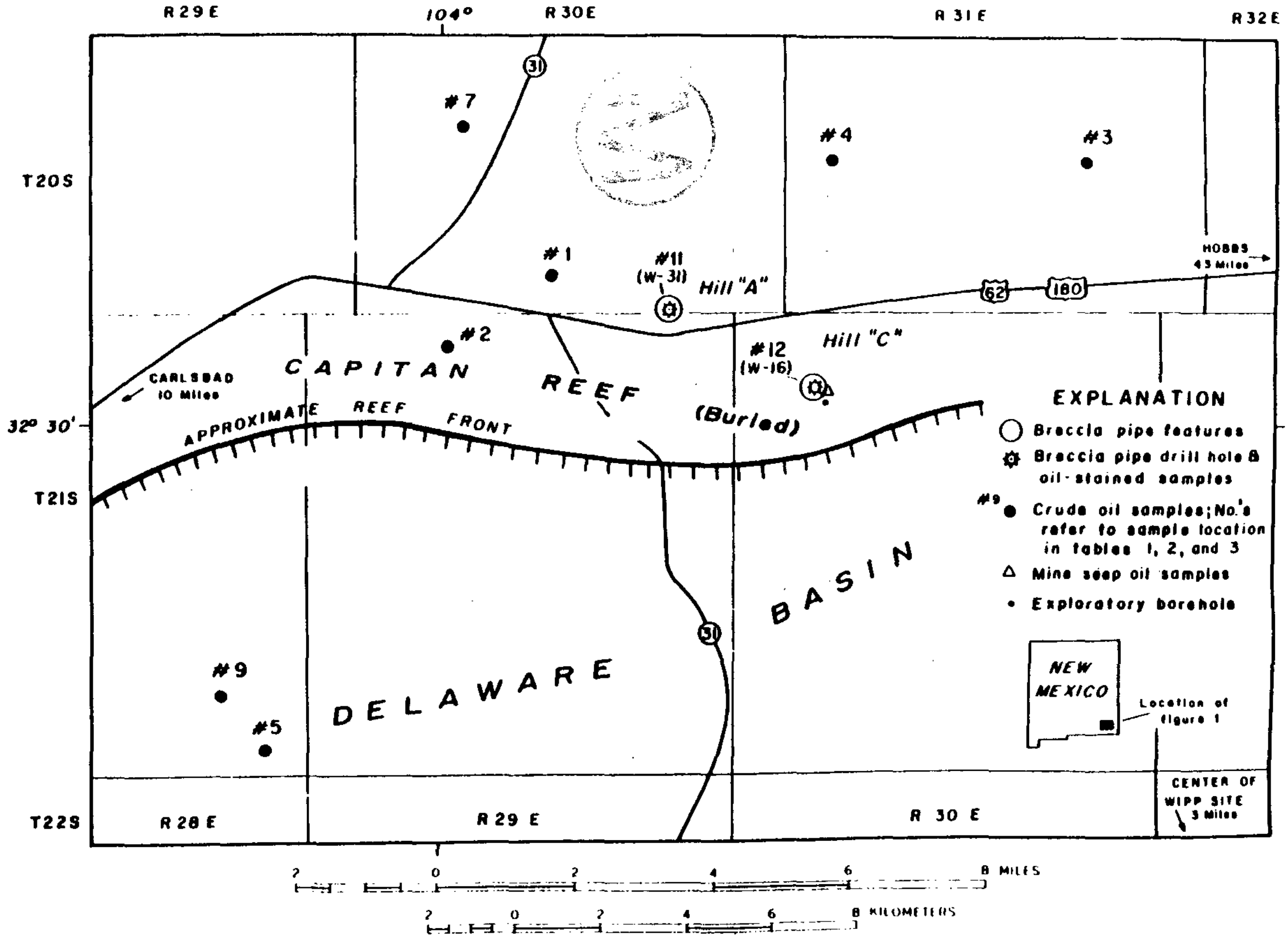

FIGURE E-2 Location of breccia pipe features; breccia pipe, mine seep, and crude oil samples; and approximate Capitan Reef front in Eddy County, New Mexico. W-16 and W-31 are drill holes at breccia pipe features. Source: Palacas et al. (1982).

sink, San Simon sink, and possibly other related karst features observed near or above the Capitan Reef in the Delaware Basin.

Hill C (Dome C in Vine 1960) and Hill A have been shown to be deep-seated "breccia pipes." R. P. Snyder (U.S. Geological Survey, personal communication to the WIPP panel, 1982) points out that they are not unlike a rubble chimney caused by the detonation of a buried nuclear device. Because of their size and potentially disruptive nature, breccia pipes require better understanding, because they are a mechanism that could affect a repository.

Drill-stem tests in borehole AEC-7 indicate that: (a) the 8 m to 10 m thick Lamar Shale Member that occurs near the upper portion of the Bell Canyon is practically impermeable, and (b) the permeability of the brine-producing zone of the Ramsey Sandstone in borehole AEC-7 is about 1.2 m/yr (Lynes, Inc. 1979). Hiss (1975) constructed a potentiometric surface map for the Delaware Mountain Group, using a large number of control points. His potentiometric surface map and chloride concentration gradients show that flow is generally to the northeast within the northern part of the Delaware Basin. The average hydraulic gradient, using potentiometric data corrected for fluid density, is about 0.0025 m/m (Wood et al. 1982) and the computed flow rates in the Bell Canyon, is about 0.135 m^3/yr per meter width of aquifer. Allowing for probable ranges in hydraulic conductivity, effective aquifer thickness and hydraulic gradient, probable flow rates were estimated to range from 0.02 to 0.40 m^3/yr per meter.

Groundwater quality analyses of samples taken from the Bell Canyon Formation reveal that chloride concentrations range from 1 to 190 kg/m^3, and that total dissolved solids typically exceed 20 kg/m^3 for much of Bell Canyon groundwater (Hiss 1975). Hiss' contours of equal chloride concentration (isochlors) roughly parallel the potentiometric surface for the Bell Canyon and increases from southwest to northeast near the WIPP site. Wood et al. (1982) and Lambert (1982) indicate that the specific source of chloride is difficult to determine, although some of it may be derived from the overlying Castile Formation, having been derived from a more regional, rather than concentrated site originating from a few distinct points, and from reactions within the Bell Canyon Aquifer. Wood et al. (1982) computed the water particle velocity to be approximately 0.03 m per year within the Bell Canyon near the WIPP site based on an average hydraulic conductivity of 1.8 m/yr, a porosity of 0.16 and hydraulic gradient of 0.0025 m/m. This travel time in the Bell Canyon from underneath the center of the WIPP site to the nearest known point on the Capitan Reef, is approximately 500,000 years. A mechanism is lacking, however, for getting nuclides into the Delaware Mountain Group (DMG). At present, heads in the DMG stand above the proposed repository level.

Wood et al. (1982) analyzed two major mechanisms for deep-seated dissolution of salt from halite horizons through the agency of an underlying aquifer at the WIPP site:

- molecular diffusion along grain boundaries and through fractures in the intervening anhydrite layer; and o *solute-driven convection*, either through a single wide fracture or through a permeable porous zone or fracture network between halite and aquifer horizons.

The latter is a worst case example similar to that postulated by Anderson.

To demonstrate the dissolution capabilities of the salt removal mechanisms, one-dimensional analytical equations describing the mechanisms of salt dissolution and their interrelationship have been applied to the Delaware Basin. Two-dimensional numerical modeling of flow and mass transport has provided a more precise study of salt dissolution in the Castile Formation and mass transfer to the Bell Canyon Aquifer. The results of the Wood et al. (1982) modeling are consistent with observed chloride concentration levels associated with dissolved halite in the Bell Canyon Aquifer (Lambert 1982). Conditions required to support dissolution within the Bell Canyon Aquifer include a concentration gradient to drive the diffusion process and a density gradient to initiate convection. Additionally, convection is dependent on the fracture size or porous zone (fracture network) permeability. As shown in the Wood et al. (1982) analysis, convection can be substantially greater than diffusion for a fracture greater than 0.0015 m, or for intrinsic permeabilities greater than 10^{-16} m^2. However, for conditions in the Delaware Basin, the Bell Canyon Formation will limit the dissolution mechanism because the concentration and density gradient will be controlled by the aquifer transport rate. The Bell Canyon Aquifer water transport rate is inadequate to transport the necessary amounts of salt implied by Anderson's original brine-density model.

Two implausible worst case scenarios were also developed by Wood et al. (1982), and the sizes of associated solution cavities estimated. Based on the calculated solution cavities, the possible implications of development of a dissolution cavity at the Halite I horizon on the integrity of the underground WIPP facility were assessed.

The following conclusions were reached:

o Observed site features which provide evidence for deep-seated dissolutioning are located at the Capitan Reef margin and consist primarily of breccia pipes. The origin of other dissolution features observed in the basin is open to interpretation, although near-surface rather than deep-seated dissolutioning appears more plausible.

o The residence time of groundwater in the Bell Canyon Aquifer is relatively long, with a flow rate which requires more than two million years to travel from recharge near the west reef margin to discharge at the east section of the Capitan Reef.

o The potential dissolution mechanisms include diffusion and convection from halite zones to the aquifers. Computation of the present dissolution rate, based on observed chloride concentration levels in the Bell Canyon, indicates that diffusion and possibly very weak convection result in the removal of halite from the Castile

Formation. However, convection may be considerably more significant at locations adjacent to the Capitan Reef Aquifer.

o Evaluation of the present DMG hydrogeologic and geochemical conditions and review of their potential range of values, indicate that halite dissolution associated with the Bell Canyon Aquifer will not impact the underground WIPP facility. A solution zone of less than 0.1 m in height was calculated, based on the maximum dissolution rate in 10,000 years.

o Based on an analysis of potential changes in the hydrologic characteristics (i.e. hydraulic gradient) of the Bell Canyon Aquifer, a possible increase in flow rate of one order of magnitude in the future would not impact the WIPP facility over the period of investigation, 10,000 years.

o Based on an analysis of the maximum potential dissolution rate associated with convective and diffusive dissolution mechanisms at the Bell Canyon Aquifer-Castile Formation interface (i.e. worst case), no impact should be observed at the underground WIPP facility during the period of investigation, 10,000 years.

The analysis by Wood et al. (1982) of deep-seated dissolution due to diffusion and convection (brine density flow; Anderson and Kirkland 1980), and the significance of the parameters which influence these dissolution mechanisms are revealing. Brine density flow or convective dissolution as a potential mechanism for removal of halite is possible in areas overlying and immediately adjacent to the Capitan Reef Aquifer where high rates of groundwater flow can occur and water is undersaturated with respect to NaCl. However, geochemical data suggest that convective dissolution by the Bell Canyon Aquifer is not very significant and results in dissolutioning at the rate no greater than associated with the diffusive dissolution mechanism. Furthermore, the very low flow rate of the Bell Canyon Aquifer and the associated salt transport rate indicate that significant convective dissolution of halite in the overlying Castile Formation would be precluded due to the inability of the aquifer to maintain the density gradient for any significant period of time (Wood et al. 1982).

The deep dissolution analysis by Wood et al. (1982) has adequately set bounds on the rates and unimportance of sub-Castile dissolution process.

Several questions remain unanswered: Where are conditions favorable for possible future breccia pipe formation? Are San Simon Sink and Kermit Sink modern examples of breccia pipes in various stages of formation? Are there possible circumstances available for renewed breccia pipe formation at or near the WIPP site? How might specific high risk sites for future pipe development be identified?

It is important to be sure that the reef facies margin immediately northwest, north, and northeast of the WIPP site is accurately known, and that there are no smaller fringing reefs present between the site and the main reef that may be hydraulically connected with it. Reef masses tend to be rather complex when traced in their development through time and space. However, no such reef occurrences were noted in test holes, and a number of industry deep well logs, borehole geophysical data, and seismic refraction data were used in test holes AEC-7 and AEC-8 to show that the southern edge of the reef is at least seven miles away from the northern edge of the WIPP site.

Judging from the importance that zones of fracture concentration have on the location of Carlsbad and other caves in the Guadalupe Mountains (Parizek 1979), similar structures also most likely contributed to the formation of caves and conduits within buried reef rock. Fracture trace and lineament related structures that intersect reef rock are major candidate sites for possible present and future sinkhole and breccia pipe development.

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APPENDIX F

SALT DISSOLUTION

Containment of radioactive wastes at the WIPP facility hinges on the long-term integrity of the evaporite section which will be subjected to persistent dissolution, to perturbation during the development of the repository and following its decommissioning, and to possible future human intrusion.

Salt dissolution can progress from the top of the salt section, from below, and within individual salt beds. The rate of dissolution is directly related to the volume of water that comes in contact with salt in a given time period, the chemical quality of this water, and the rate at which dissolved salt can be transported within and from the aquifer. On a geological time scale, the dissolution can be rapid. Few outcrops of soluble salt beds are ever observed in humid regions or even in moderately arid regions because the shallow, unprotected salt has long since been leached away. However, salt that is deeply buried, or covered by poorly-permeable strata that restrict groundwater circulation, can survive for long periods of geological time even in basins with active groundwater circulation. Permian-aged salts of the Delaware Basin of New Mexico and west Texas are good examples, for they have persisted for more than 200 million years despite active dissolution at some points.

Reliable estimates of the total amount of Salado and Castile evaporites removed to date by dissolution are difficult to make because of (a) original heterogeneities of deposition, (b) ambiguous identification of members or marker beds, (c) partial removal of halite by dissolution or early subaerial erosion, and (d) perturbation of original bedding thicknesses by localized deformation (Lambert 1982).

Episodes of uplift accompanied by erosion and dissolution of evaporite beds are described by Powers, et al. (1978):

> Periods of terrestrial deposition alternated with erosional episodes, so that a series of non-marine deposits separated by angular unconformities blanket the evaporite beds at the site. These angular unconformities represent intervals during which salt beds at the WIPP site were tilted and subjected to potential dissolution. At least four erosional episodes separated by depositional intervals are recognized: (1) early

> Triassic time in which the Dewey Lake Redbeds were tilted and eroded to a slight angular unconformity before deposition of the Upper Triassic Dockum Group; (2) Jurassic-Early Cretaceous time in which the Dockum Group was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous); (3) a Late Cretaceous through mid-Tertiary erosional interval when the region was again tilted and the Triassic Dockum Group of sediments was bevelled for a second time; and (4) a post-Ogallala (post-Pliocene) uplift and erosion in early Pleistocene time, prior to which deposition of the (Kansan?) Gatuna formation took place. Subsequent to deposition of the Gatuna, there probably were pluvial intervals corresponding to the Illinoisian and Wisconsin glaciations during which accelerated erosion in these wetter times occurred in the area of the WIPP site.

Each period of tilting, which was accompanied by the potential for renewed erosion, also afforded an opportunity for salt flow by plastic deformation along the imposed gradient and salt deformation as the salt impinged against reef abutments or responded to uneven, differential sediment loading or erosional unloading. Salt deformation of this type may account for the origin and distribution of isolated pressurized brine reservoirs found in the Castile. To the extent that some "deep dissolution" features are recognized today in salt at depths of several thousand feet below the surface, it seems likely that subsurface dissolution of salt could have been initiated at comparable depths beneath the surface as soon as early-Triassic time. Episodes of active dissolution most likely occurred during the Jurassic and late-Cretaceous-to-mid-Tertiary erosional intervals, as well as during the several pluvial periods corresponding to Pleistocene glacial stages.

Recent regional rates of salt removal from the top and bottom of the Delaware Basin evaporite have been estimated from a knowledge of salt dissolution mechanisms, regional groundwater flow systems, and the geochemistry of its groundwaters (Powers et al. 1978; Wood et al. 1982). Concentrated, more localized dissolution processes may give rise to breccia pipes, such as Hills A and C (Figure E-2, Appendix E), and sinkholes, such as San Simon Sink, Kermit (Wink) Sink, and other large-scale, deep-seated karst features. Some of these karst features formed in part in a localized catastrophic manner rather than by slow regional subsidence. Abrupt collapse of large volumes of consolidated and unconsolidated strata, as occurred at San Simon and Kermit Sinks, is possible only where void space formed at depth by slow differential dissolution of soluble strata. Each of these salt dissolution processes will be reviewed briefly as they pertain to the long-term geological stability of WIPP.

The present rate of salt dissolution has been estimated for the top of the halite within the Rustler and Salado Formations (Powers et al. 1978; Bachman 1974, 1980), and more recently for the base of the Castile

Formation at the Castile-Delaware Mountain Group contact (Wood et al. 1982). Many lines of convergent evidence were reviewed by Wood et al. (1982) and Lambert (1982) to help bound rates of salt dissolution. Local and basin-wide stratigraphic and structural observations were considered in these analyses, as well as mineralogical and textural relationships observed in caves and cores. Lambert (1982) presented additional data obtained from chemical and isotopic analyses of rocks and solutions regarding equilibrium relationships of brines and other groundwaters obtained from various sources in the Delaware Basin. These lines of evidence provide support for estimates of dissolution rate that previously were based largely on stratigraphic and geomorphic evidence. Additional evidence regarding dissolution rate is currently being sought from incongruent phase relations (Lambert 1982).

Erosion by solution and fill is a mechanism originally proposed by Lee (1925) for shallow dissolution of gypsum terrain, characterized by incision of dendritic drainage patterns and development of underground drainage channels that collapse as soluble materials are dissolved. Bachman (1980) thinks that this mechanism is active in sections of the Delaware Basin underlain by gypsum, resulting in a chaotic jumble of less soluble rock as an end product.

Bachman (1980), Christiansen (1971), Jagnow (1979), and others describe a shallow process of phreatic dissolution of soluble rocks within open conduits which contain freely circulating groundwater that is undersaturated with respect to the rocks (such as carbonate rocks, anhydrite, gypsum, and halite) being dissolved. This process is differential in nature and can produce large open cavities, such as Carlsbad and related caverns in the Guadalupe and Delaware Mountains and smaller cavities noted in Nash Draw. Many of these caverns in the Capitan Limestone exhibit structural control, i.e., zones of fracture concentration, which are also likely to influence present development of solution permeability within Capitan Reef rock where buried by Salado, Rustler, and other strata. Similar zones of fracture concentration are present in the back reef sediments of the Artesia Group that lies shelfward of the Capitan Reef and appear to have helped to localize numerous sink holes and collapse structures.

A different origin for some karst deposits and landforms is proposed by Anderson (1978). He suggests that many of these features were created by deep-seated solution activity, which he thinks is an ongoing process within the Delaware Basin. He believes that the region of concentrated salt dissolution activity has migrated from west to east through geologic time, as well as along and away from the margins of the Capitan Reef. In support of his hypothesis of deep-seated dissolution, Anderson cites the presence of many sinks, domes, and breccia pipes in various parts of the Delaware Basin, and the thinning of halite layers I, II and III deposits in the Castile Formation near the western margin of the basin.

As a corollary of the deep-seated dissolution hypothesis, Anderson and Kirkland (1980) proposed a brine-density flow model to account for breccia pipes in the Delaware Basin. For this mechanism to operate, fractures must expose the base of the evaporite section to undersaturated solutions that begin to dissolve salt. As salt dissolves, water becomes more dense and sinks into the lower part of the aquifer, allowing new unsaturated waters to come in contact with the salt in a self-perpetuating manner. Overlying strata collapse into the cavity created by the dissolution. As the aquifer providing the undersaturated solution, Anderson and Kirkland suggested the Bell Canyon Formation, which immediately underlies the salt sequence.

Recent work, however, has cast doubt on the ability of the Bell Canyon Formation to supply the necessary flow of undersaturated fluid (Lambert 1982; Wood et al. 1982). Five lines of evidence are presented by Lambert (1981) to show that the Bell Canyon is an unimportant aquifer:

- o extremely limited quantities of water produced from but a few thin Bell Canyon Formation horizons;
- o Bell Canyon water is highly saline, but not completely saturated with sodium chloride under the evaporites (Hiss 1975);
- o the salinity does not rise abruptly from west to east as evaporites appear in the overlying section (Hiss 1975);
- o the water contains solutes in combinations not found in the evaporites (Lambert 1978); and
- o there is little evidence for appreciable movement of water in the Bell Canyon (Mercer and Orr 1979).

Anderson (1982a) now agrees that the Bell Canyon is an unlikely source of solutions for the brine-density mechanism, and suggests instead that deep dissolution is concentrated in layers of fractured anhydrite near the Salado-Castile contact. The alleged flow in this layer, called "blanket" or "stratabound" dissolution, involves the lateral movement of water along a permeable bed, adjacent to which soluble rock dissolves. More rock dissolves as new void space is created. Such dissolution in this and other anhydrite beds, according to Anderson (1981b), has removed nearly 50 percent of the halite in the Delaware Basin by a process that he thinks is still active and still proceeding eastward at significant rates. More recently, Anderson (1981b, 1982a) has tied this process to the origin of brine reservoirs in Castile anhydrites as well. He has dropped the Bell Canyon as an important aquifer for significant salt removal and breccia pipe formation as proposed in his earlier papers.

Bachman (1980) and Lambert (1982) agree that stratabound dissolution occurs, but think that it operates only near to points of recharge where waters are more likely to be undersaturated with salts and where groundwater sinks are available for salt and water removal. They do not agree with Anderson that this mechanism is widespread or is responsible for pressurized brine reservoir formation. To date, no evidence has been provided to show that anhydrite beds within the Castile or Salado Formations serve as regionally interconnected aquifers in the basin.

Hydraulic heads in the Bell Canyon Aquifer stand above the proposed repository level and no foreseeable mechanism exists for introducing radionuclides into the Bell Canyon. Extraction of oil and mostly gas in the northern section of the Delaware Basin has not caused a drawdown in potentiometric heads within sub-Bell Canyon reservoirs that have reversed hydraulic gradients in the Bell Canyon. Also, estimated flow rates in the Bell Canyon show that nearly 500,000 years may be required for its waters to move from beneath the WIPP site to the Capitan Limestone Aquifer, assuring that it is hydraulically interconnected to the Bell Canyon Aquifer.

The Capitan Limestone is an important aquifer, with extensive solution porosity where exposed west of the WIPP site as well as where buried in the northern and eastern margin of the Delaware Basin. Hiss (1975) reports high porosity zones within buried reef rock as shown by five occurrences of bit drops during drilling of 3.6 to 18m (12 to 60 ft). Hiss' model for regional groundwater flow within the Capitan Limestone and adjacent strata has been modified by Lambert (1982) to be consistent with current isotopic data. Lambert concludes:

- virtually no involvement of the Bell Canyon exists in either groundwater recharge or discharge from the Capitan;
- the reef shelf system may be divided into various units that can act as either recharge or discharge areas for the Capitan; and
- the Bell Canyon Formation is not being actively and continuously recharged by any known meteoric or groundwater source in the Delaware Basin as revealed by isotopic data (Lambert 1978).

All current lines of evidence have led Lambert (1982) to conclude that water movement in the Bell Canyon, Castile and Salado Formations in the north central Delaware Basin is either imperceptibly slow or non-existent and that stratabound dissolution in unspecified beds, most likely anhydrite layers, is the most plausible model for efficient removal of evaporites at depth. What to do with the saturated brine of dissolution origin remains a major problem with the stratabound model. This is the same issue on which Anderson's thesis is vulnerable. A plausible water and solute sink needs to be located for salt to be removed.

Dissolution processes described by the Lambert model are not likely to disrupt surface support facilities during operation of the facility, but in time, could increase the permeability of the Magenta and Culebra Dolomite Members within the Rustler Formation as salt is slowly dissolved from the Rustler and the top of the Salado. This could influence the permeability of the Rustler Formation near the upper portions of shafts and borehole seals following backfilling of the repository. Permeability increases within any of the Rustler units will: (a) increase groundwater flow rates, (b) accelerate rates of salt dissolution by a feedback loop mechanism, and (c) reduce the thickness of the protective salt layer above the proposed repository. None of these changes, however, are likely to be significant under present climatic conditions or before TRU wastes decay to acceptable levels.

The formation of a breccia pipe under a repository according to Anderson and Kirkland's (1980) model might have caused serious disruption. The work of Wood et al. (1982), however, greatly restricts the location in the Delaware Basin where breccia-pipe formation might be possible; i.e., above the permeable Capitan Limestone. The distribution of the Capitan Limestone and its southern limits are well known. The northern outer edge of Zone IV is at least 7 miles south of the mapped southern extension of the reef; hence, there is no chance for a future Capitan Reef breccia pipe to disrupt the repository.

Anderson's (1982a) hypothesis for intraformational removal of salt well within the basin is difficult to test. He concludes that fractured anhydrite beds observed within the Castile Formation are regionally interconnected, and that they serve as aquifers containing actively circulating water that may be quite young and is capable of dissolving significant amounts of salt. Lambert's (1982) stratabound hypothesis is testable, but not enough data have yet been compiled to support a final conclusion. However, the many cores taken from Castile anhydrite beds do not show open fractures and brine except where brine reservoirs have been encountered along anticlinal structures near the Capitan Reef. This suggests that brine reservoirs are genetically related to folding of evaporite beds and derive their built-in and confined pressures from sources other than from existing groundwater recharge areas. Many oil and gas industry wells in the basin have been geophysically logged. These do not show brine saturation within the Castile anhydrite beds nor did they penetrate brine reservoirs. These observations weaken the argument that most oil and gas wells just missed open fractures inferred to be present and widely distributed.

Shut-in pressures measured for brine reservoirs also are high enough to induce artesian flows. If fractured anhydrite reservoirs served as regionally interconnected aquifers within the Delaware Basin, these pressures could not be sustained for prolonged periods of time. This also indicates that overlying salt beds are poorly permeable.

Powers et al. (1978), Register (1981), and others regard the Castile Formation as an aquiclude that isolates poorly permeable Delaware Mountain Group aquifers from overlying Rustler Aquifers and the Salado Formation. Wastes are to be contained in salt beds of the lower Salado Formation, which is located between these aquifers (Figure 1-2). The porosity of Salado halite and the underlying Castile Formation is very low and interconnected pores are virtually non-existent (Register 1981).

Although open fractures are precluded in individual salt beds by the viscoelastic-viscoplastic behavior of salt, small openings containing both brine and gas can exist between grains of halite, and small pockets of brine may be encountered. Fluid inclusions also are present on a much smaller scale. Less common are the larger cavities and pockets containing halite-saturated brine and associated gas which have been encountered in Castile anhydrites. These pressurized brine reservoirs are under enough pressure to displace drilling fluids and brine to surface when encountered during drilling. The quality of record describing these occurrences is variable, especially with respect to brine flow rates and initial downhole pressures (Register 1981). All of the larger occurrences of brine appear to be confined to the Castile Formation, although smaller brine pockets have been encountered in the Salado Formation. Griswold (1980) indicates that no written records are available that describe these Salado encounters; however, from accounts given by miners who have worked the McNutt potash, the pockets have been reported as small and not highly pressurized. Estimated brine volumes in three mines are 720 m^3 (190,000 gal) (PCA mine, 17 miles from the

WIPP site); 9.5 m^3 (2,500 gal) (Duval Nash Draw Mine, 5 miles from the WIPP site); and 57 m^3 (15,000 gal) (Kerr-McGee Mine, 10 miles from the WIPP site), according to the Safety Analysis Report (SAR) (U.S. Department of Energy 1980-1982). When encountered, the Salado pockets are allowed to bleed into the mine until depleted before mining is resumed. Routinely, shallow boreholes are drilled into roof strata in potash mines to explore for and bleed off such fluids under controlled conditions. This same practice will be followed during repository development following initial more elaborate development of test holes drilled in advance of the working face during early stages of repository development. All such fluids are to be removed from the repository (U.S. Department of Energy 1980-1982).

Register (1981) summarizes pressurized brine pocket occurrences in the Castile Formation in the vicinity of the WIPP site (Figure F-1, Table F-1). These pockets, usually associated with hydrogen sulfide gas, have been encountered mainly in the Castile Formation (exploratory holes ERDA-6, AEC-7 and WIPP-12) by various oil and gas drilling companies and Sandia National Laboratories. Register reports that of 62 deep boreholes drilled into the Castile Formation, ten (16 percent) penetrated pressurized brine reservoirs. All brine encounters, except AEC-7 that flowed only one or two liters of brine and hence should be excluded from the list, flowed to the surface with initial rates estimated between 600 and 200,000 barrels per day and initial downhole pressures of from 1,630 to 2,222 psi. Snyder (1982) shows that in each case where stratigraphic data are available, Castile brines issued from the Anhydrite III member, or the uppermost anhydrite in those wells where all anhydrite members are not present. Nine of these ten occurrences were associated with the deformation front abutting the Capitan Reef. Eight of the nine were associated with known anticlinal structures in the Castile Formation. The other occurrence (Belco - Federal) is located about three miles southwest of the WIPP site and is closely associated with an anticline. A much smaller probability of penetrating a pressurized brine reservoir within the Castile Formation is noted if one draws a circle about the WIPP site, with a radius large enough to circumscribe up to 350 deep oil and gas wells and outermost brine reservoirs. In this case, only a 3 percent chance of occurrence is noted (W. D. Weart, Sandia National Laboratories, personal communication to the WIPP Panel 1982).

The deepening of the WIPP-12 borehole to the basal Castile member (Anhydrite I) resulted in the interception of a brine reservoir at a depth of 919 m (3,015 ft) within fractures in Anhydrite III. The shut-in pressure recorded at the well prior to substantial brine removal, was 0.014 N/m^2 (208 psi). On April 15, 1982, the shut-in pressure after brine removal was 0.012 N/m^2 (168 psi) and still rising. For this reason, no final estimate was made on the WIPP-12 reservoir volume by Black et al. (1982). R. S. Popielak, D'Appolonia Consulting Engineers, Inc. (personal communication to WIPP Panel 1982), indicated that the well-head pressure appeared to have stabilized at about 0.012 N/m^2 (170 psi) by May 17, 1982. Preliminary analysis of the WIPP-12 reservoir volume suggests it may have a capacity on the order of 5×10^5 m^3 (3×10^7 bbl), but the well may still be

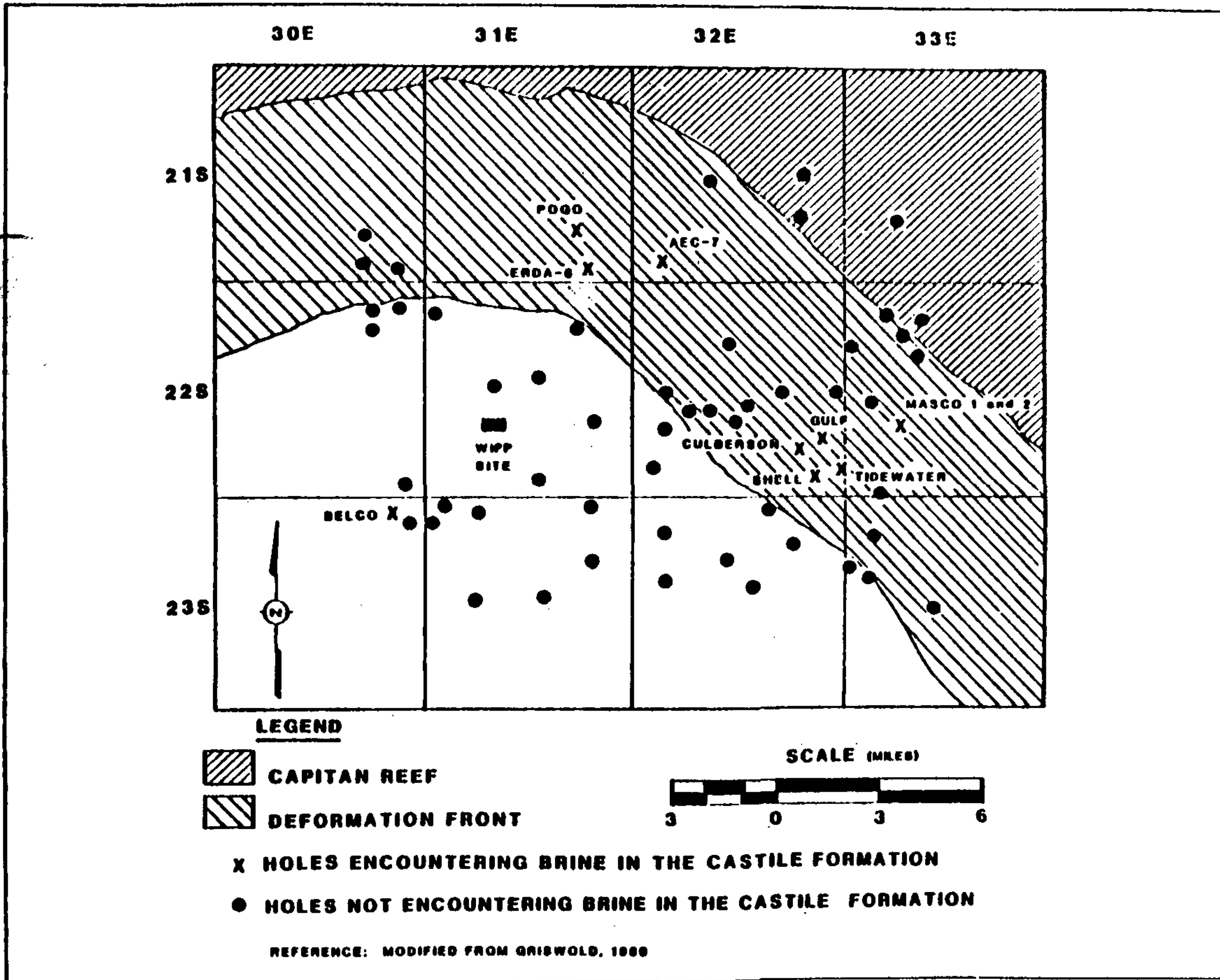

FIGURE F-1 Location map of deep boreholes in WIPP site vicinity. Source: Register (1981).

TABLE F-1 Brine Pocket Data

WELL DESIGNATION (Ground Elev., ft)	LOCATION (Sec. T.R.)	YEAR DRILLED	BRINE DEPTH (ft)	RESERVOIR PRESSURE (psi)	INITIAL FLOW (bbl/day)
ERDA-6 (3,540)	35 21S 31E	1975	2710	1900(2)	660
AEC-7 (3,662)	31 21S 32E	1979	Unknown	No Flow	No Flow
Belco (3,298)	1 23S 30E	1974	2802	2075(3)	12,000
Culbertson-1 (3,727)	26 22S 32E	1945	3515	1860(2)	3,000(4)
Gulf (3,761)	25 22S 32E	1975	3600	2010(3)	5,000(4)
Mascho-1 (3,621)	20 22S 33E	1937	3320	1760(2)	8,000
Mascho-2 (3,618)	20 22S 33E	1938	3240 3298	No Flow 1750(2)	No Flow 3000
Pogo (3,533)	26 21S 31E	1979	3322	2260(3)	1440(5)
Shell (3,775)	36 22S 32E	1964	3671	1950(2)	20,000
Tidewater (3,755)	36 22S 32E	1962	3730	2330(2)	Not Available

(1) Data from oil drilling histories filed with the USGS.
(2) Minimum pressure to displace saturated brine or drilling mud from the well.
(3) Pressure measured at the well head with a full column of mud.
(4) Total volume of brine flow to surface.
(5) Flow during circulation of 14.8 pounds per gallon drilling mud.

SOURCE: Register (1981).

building up pressure; hence, this estimate is regarded as only approximate. Assuming that its storage space is 5 x 10^5 m^3 (3 x 10^7 bbl), and using other assumptions that have not been verified, one can estimate a value of 1 km for the approximate radius of this brine reservoir. The WIPP-12 borehole is located on an anticline where the brine occurs 275 m (900 ft) to 290 m (950 ft vertically below and a minimum horizontal distance of 170 m (558 ft) from the proposed waste storage facility. Given the apparent size of this brine reservoir, it is reasonable to assume that a portion of it may underlie a facility oriented northward from the shaft.

What are the potential consequences, if any, of such a brine reservoir to the WIPP facility? This depends upon (1) the chances for brine communication between such reservoirs and the repository during its development; (2) chances for communication following closure and accidental man-made penetrations; and (3) the potential for concentrated, significant, and rapid salt dissolution immediately above such pressurized brine reservoirs that may help expose wastes to a regional groundwater flow system. The only plausible mechanisms for communication between this WIPP-12 Castile brine reservoir and the operating facility would be through (a) the encounter or development of extensive vertical fractures within salt and anhydrite located between the brine reservoir and repository; (b) the existence of unknown, unplugged, or inadequately plugged boreholes; or (c) the development of new fractures by whatever mechanism during repository development. Penetration by drilling would pose the greatest risk following closure and is the only mechanism that appears mechanically possible for breaching deep brine reservoirs in the near geological future.

The viscoelastic-viscoplastic behavior of salt under confining pressures present at repository and greater depths, precludes the presence of open, water-bearing fractures in rock salt. There is no known mechanism that would allow for the development and persistence of rock fractures in the salt beds that could serve to channel brine between the WIPP-12 reservoir and a working repository. The very presence of high pressure brine and gas reservoirs supports strongly the lack of, or extremely limited nature of, vertical or horizontal connectedness.

Estimates of initial downhole pressures for various flowing brine wells range from 1,630 to 2,322 psi. These pressures are insufficient to hydrofracture the nearly 265 m (870 feet) of salt and anhydrite that separate the WIPP-12 brine reservoir from the proposed repository at this depth. This is also true when the repository is under atmospheric conditions during development. For these reasons, WIPP-12 brines should remain confined, even if the repository were to lie directly above the brine reservoir.

No oil and gas wells that penetrate the evaporite sequence are known to exist within Zone III at the WIPP site. The chances of one or more unplugged wells venting these brines into the repository during development are minimal because major test well sites and access roads are hard to obscure in the desert environment. Scars from these activities persist for years and are easy to detect. Further, if unplugged wells did exist, there should be ample evidence of brine discharges, such as vegetation kills, salt pans, and erosion gullies.

Finally, chances for strata-bound dissolution of salt above the WIPP-12 brine reservoir in Anhydrite III, as suggested by Anderson (1981a), and the breaching of the repository from below are very remote. Castile brine pockets have the highest hydrostatic heads of any groundwaters measured in the region. For this reason, Black et al. (1982) concluded that these pockets cannot receive recharge from other nearby sources. The erratic differences between hydrostatic heads observed within individual brine pockets and their geographic and stratigraphic separation suggest no communication between individual brine pockets. Flow data from the ERDA-6 borehole indicate a finite reservoir. The apparent permanent pressure drop within this brine pocket, associated with a measured amount of discharge, indicates to Black et al. (1982) and others a completely bounded and isolated reservoir that receives no detectable recharge. Further, the lack of a pressure response there during flow testing at the WIPP-12 borehole only four miles away, also indicates that these are isolated brine pockets, despite their large sizes. Erratic head variations noted for Castile brine reservoirs, the unique geochemistry and isotopic content of their fluids, their limited volume estimated from flow test data, and the lack of pressure responses in adjacent wells during flow tests all suggest that brine pockets are not regionally interconnected (Black et al. 1982). These authors also note that brine reservoirs are found only in anticlinal structures, the vast majority of which are closely associated with the Capitan Reef disturbed zone. In all probability these pockets are isolated, and diagenetically-pressurized from lithostatic loads, biogenetic gas generation, and/or reaction of gypsum to anhydrite plus water.

The evidence cited indicates that the chance of significant strata-bound deep dissolution of the Castile and Salado Formations by pressurized brine reservoirs from above or below is small, and that the likelihood of pressurized brines communicating with the repository during its development is minimal.

A more plausible mechanism for nuclide release would be penetration of both the repository and a pressurized brine reservoir by drillholes following closure. This could lead to release of pressurized brine along a drill hole into the repository, and then to the land surface or into one or more Rustler Aquifers.

The consequences of this scenario (Scenario II) were considered by Woolfolk (1982), and were reviewed by the panel. It was assumed that 200 years elapsed before drilling, brine had entered a single room containing backfilled water as a result of the drilling of one well, pressurized brine flowed into the room, and up to 342 cubic feet of contaminated brine was released to the surface. The conclusion was that no significant impact to public health and safety would result (G. L. Bohmann, Westinghouse Electric Corporation, personal communication to the WIPP panel 1982).

It is entirely reasonable that at least some porosity and permeability will persist within backfill and between waste containers for 200 years following closure and that these pore spaces will become saturated in time. The presence of confined water during the salt creep filling of residual pore space should preclude the complete loss of permeability in backfill materials before 200 years; hence the backfilled repository environment is expected to remain more permeable than the original salt for some years to come. Under lithostatic loading, brine-filled pore spaces should tend to close, thereby reducing permeability, but processes of pressure solution should tend to maintain porosity. The rate at which repository induced porosity and permeability will be reduced following backfilling in the presence or absence of brine cannot be reliably predicted, as selection of backfill materials and methods of emplacement are still under consideration.

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REVIEW OF THE SCIENTIFIC AND TECHNICAL CRITERIA FOR THE WASTE ISOLATION PILOT PLANT

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Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (WIPP)

Panel on the Waste Isolation Pilot Plant
Board on Radioactive Waste Management
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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PANEL ON THE WASTE ISOLATION PILOT PLANT (WIPP)

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BOARD ON RADIOACTIVE WASTE MANAGEMENT

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

CONTENTS

PREFACE

In March 1978 the U.S. Department of Energy (DOE) asked the National Research Council "to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere." The National Research Council assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources (now the Board on Radioactive Waste Management under the Commission on Physical Sciences, Mathematics, and Resources). The committee organized the Panel on the Waste Isolation Pilot Plant to "review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

In July 1978, when this study began, the Waste Isolation Pilot Plant (WIPP) was to be a mined repository in bedded salt in Eddy County, New Mexico, for the disposal of transuranic (TRU) waste, with experimental facilities for studying the interactions of high-level waste with the host rocks. At that time, use of this repository for disposal of a limited number of commercial spent-fuel elements was also being considered, although this was not part of the project's mission. This option was discussed frequently in technical briefings of the panel and in supporting documentation. The panel has examined some of the generic issues related to this possible course of action, as well as those concerns raised solely by the proposed disposal of transuranic waste in the particular salt formations at the WIPP site; but current plans do not include use of the facility for disposal of commercial waste.

The panel issued an interim report (National Research Council 1983) recounting its findings through the end of July 1982. By that time, several major WIPP program documents had been issued, including the Geological Characterization Report (Powers et al. 1978), the Title I Design Report (Bechtel National, Inc. 1979), the Final Environmental Impact Statement (U.S. Department of Energy 1980), the Safety Analysis Report (U.S. Department of Energy 1980-1983).

The panel's final report evaluates work through December 31, 1983, and is based on analysis of the contents of documents issued to that date, technical briefings, discussions with representatives of DOE and its contractors, comments by interested members of the public, and a number of field visits.

CONCLUSIONS AND RECOMMENDATIONS

The panel has evaluated the scientific and technical adequacy of work being done on the Waste Isolation Pilot Plant (WIPP) project to satisfy the charge to the panel set out in Chapter 1. The panel concluded that the scientific work has been carried out with a high degree of professional competence. The panel notes that the geology revealed by shaft sinking and excavation of drifts and the preliminary measurements generally confirm the geologic expectations derived from surface explorations and boreholes. The purity and volume of the salt, the absence of brine pockets at the repository horizon in the areas excavated, the absence of breccia pipes and of toxic gases, and the nearly horizontal bedding of the salt indicate that a repository can be constructed that will meet the geologic criteria for site selection. Thus, the important issues about the geology at the site have been resolved, but there remain some issues about the hydrology and design of the facility that should be resolved before large-scale transuranic (TRU) waste emplacement begins.

Some engineering aspects of the many WIPP studies by the U.S. Department of Energy (DOE) and its contractors have not yet reached the final stage, so the panel's conclusions on these matters are likewise not final. The final design will need to incorporate the findings of the experimental program and construction activities, or it will have to be shown that findings in the experimental program, if different than predicted (e.g., the larger amounts of water in Marker Bed 193, unexpected rates of closure in the drifts, and the permeability of the backfilled drifts), will not affect the safety of the repository.

The packaging of waste at the originating sites, transport to the site, transport vehicles, and disposal of heat-generating waste are beyond the scope of this study and are not dealt with in this report.

The health and safety consequences of the postulated repository failure mechanisms appear to be so minimal that simplifications in design may be justified, and cost-effectiveness studies should be carried out to determine whether they would be acceptable. However, the probability and the consequences of potentially rapid flow of brine solutions, containing radionuclides, through more permeable formations have not been completely determined. Once these have been resolved, conventional safety considerations (e.g., number of shafts and packaging of waste for highway transport) might determine the optimum design.

Relaxation of the WIPP waste acceptance criteria (e.g., elimination of the incineration of some of the waste at the Process Experimental Pilot Plant (PREPP) facility and removal of the requirement for the use of steel-case overpack of the wooden boxes) may also have minimal consequences.

Although the panel's conclusions and recommendations appear at the end of each chapter, they are collected in this section for the reader's convenience.

CONCLUSIONS

Chapter 2: Site Selection and Characterization

o The presence of hydrocarbon and potash resources at the WIPP site is not a seriously adverse feature, because it should be feasible to recover much of the potash from the former Zone IV and the hydrocarbons from under the entire site by oblique drilling without harm to the repository. The effects of such extraction can be evaluated on a case-by-case basis (p. 11).

o Long-term tectonic quiescence at the WIPP site seems assured by its great distance from faults of recent displacement and areas of volcanic rocks, and by the lack of evidence of major seismic events nearby (p. 11).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it should not present a significant risk to the repository (pp. 11, 13).

o Evidence is good that, for a period of more than a million years, karst-forming processes are unlikely to expose the repository (pp. 13-14). Further studies will determine if the karst is likely to affect hydrologic transport in the site area.

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause breccia pipe formation indicates that the likelihood of encountering an old pipe or of a new one forming near the WIPP site is practically nonexistent (pp. 14-15; see also Appendix E).

o Evidence seems good that the strata below the salt beds (the Bell Canyon Formation) cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could they be responsible for extensive interstratal dissolution (pp. 15-17).

o The preponderance of evidence does not support the hypothesis that large-scale interstratal dissolution might endanger a repository at the WIPP site (pp. 16-19).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are isolated pockets of fluid not connected with or residual from solutions that have recently moved, or are moving for long distances through the formation (p. 19). Even if the pressurized-brine reservoir encountered in the WIPP-12 borehole in the Castile Formation were to extend directly beneath the WIPP site, this should not adversely affect the operating facility, and the existence of this reservoir is insufficient justification to stop the WIPP project.

Chapter 3: In-Situ Tests and Experiments

o The in-situ test program is logically designed to explore the local waste package-repository interactions that would result from the emplacement, retrieval, and long-term isolation of TRU and high-level defense waste in salt beds (pp. 22-30).

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in an underground salt repository at depth, is an important aspect of the WIPP program (p. 29).

Chapter 4: Waste Acceptance Criteria

o The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (p. 34).

o Criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity (p. 36).

o If the repository should become flooded with brine, the presence of sulfates might entail a new scenario: the biological generation of hydrogen sulfide and chemical dissolution of the steel drums, with generation of hydrogen (p. 37).

o From the viewpoint of the WIPP facility, the quality assurance system is inadequate in that it requires no on-site verification of conformance of package contents to the certification (p. 40).

o The Certification Committee procedure is cumbersome and may even be counterproductive (pp. 39-40).

o The PREPP incineration process appears to be an appropriate and practical technology for processing contact-handled waste that cannot be certified in the original packages (pp. 40-41).

o No procedure has been established for dealing with uncertifiable remotely handled waste (p. 41).

Chapter 5: Design and Construction of Underground Facilities

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 45).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 45).

o Recently, the repository design has changed from four to three shafts. Although the three-shaft design appears to be functionally adequate, it does not possess the flexibility and redundancy of the four-shaft design (p. 49).

Chapter 6: Performance Assessment

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (p. 52).

o The long-term release scenarios, shown in Figures 6-1 to 6-5, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within permissible limits for the general population (170 mrem whole body) and far below the dosages from normal background radiation (average over 50 years of 5,000 mrem) (p. 58). Further analyses will be needed to conform to the Environmental Protection Agency (EPA) requirements.

RECOMMENDATIONS

Chapter 2: Site Selection and Characterization

o Each proposal to develop resources in the former Zone IV should be examined rigorously on a case-by-case basis, with the burden of proof as to its safety resting on the proposer. The U.S. Department of Energy should obtain the right to deny mineral extraction from the salt beds and hydrocarbon extraction from deep levels below the salt in the old Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 10-11).

o To test the extent of deep strata-bound dissolution, the plans of Sandia National Laboratories for further field and analytical work should be implemented (pp. 17-18).

Chapter 3: In-Situ Tests and Experiments

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU waste at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU waste (p. 29).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Outside developments in automated sensing, robotics, instrumentation in hostile environments, and so on, should be systematically screened for application or testing at the WIPP facility (pp. 29-30).

o Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation (p. 29).

o Separate radiation-monitoring equipment should be installed for the experimental rooms and the TRU waste emplacement areas (p. 29).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 30).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate that form of testing so that the matrix of tests can be expanded by the less expensive laboratory experiments rather than by further in-situ testing (p. 30).

Chapter 4: Waste Acceptance Criteria

o As soon as is feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 32).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (p. 34).

o The existing deficiency in the Safety Analysis Report (U.S. Department of Energy 1980-1983) on procedures for fighting transient underground fires should be remedied (p. 34).

o The humidity of still air in equilibrium with the salt and the pH of moisture in contact with the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 36).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (pp. 35-36, 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (pp. 35-36).

o The certification procedures, especially those for inspection of waste packages upon delivery to WIPP, should be redesigned to simulate those used commercially in the purchasing of commodities (p. 39).

o Procedures should be established for dealing with (1) uncertifiable remotely handled waste and (2) high-curie contact-handled waste (pp. 37-38).

o Waste acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The criteria should be written early enough to allow time for review before experimental operations begin (p. 41).

o Consideration should be given to relaxing the waste acceptance criterion relating to gas generation due to bacterial action (p. 38).

Chapter 5: Design and Construction of Underground Facilities

o Results from the Site and Preliminary Design Validation (SPDV) and in-situ experiments and information gathered during construction and development to final design must be incorporated with the final design of the WIPP repository (p. 44).

o Models should be used to assess whether or not closure of the excavations and consequent encapsulation of the waste in salt are likely to occur, and to determine the period of time within which they may occur (p. 48).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 48).

o The Final Environmental Impact Statement (U.S. Department of Energy 1980) should be reissued to correspond with the present design (p. 49).

Chapter 6: Performance Assessment

o Though karst-type flow in the strata above the salt beds (the Rustler Formation) is known to occur near Nash Draw several kilometers to the west, the extent to which it reaches eastward is not delineated clearly. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be reduced sharply. The probability of such flows, their degree of development east of the Pecos River, and the effect of such flows upon radiation dosages need to be determined (pp. 58-60).

o For consistency, and to permit direct comparison among all the modes of release, it would be useful if all dosages were calculated on the same basis (i.e., if recommendations of ICRP-26 and ICRP-30 were used, rather than those of ICRP-2) (pp. 58-59).

CHAPTER ONE

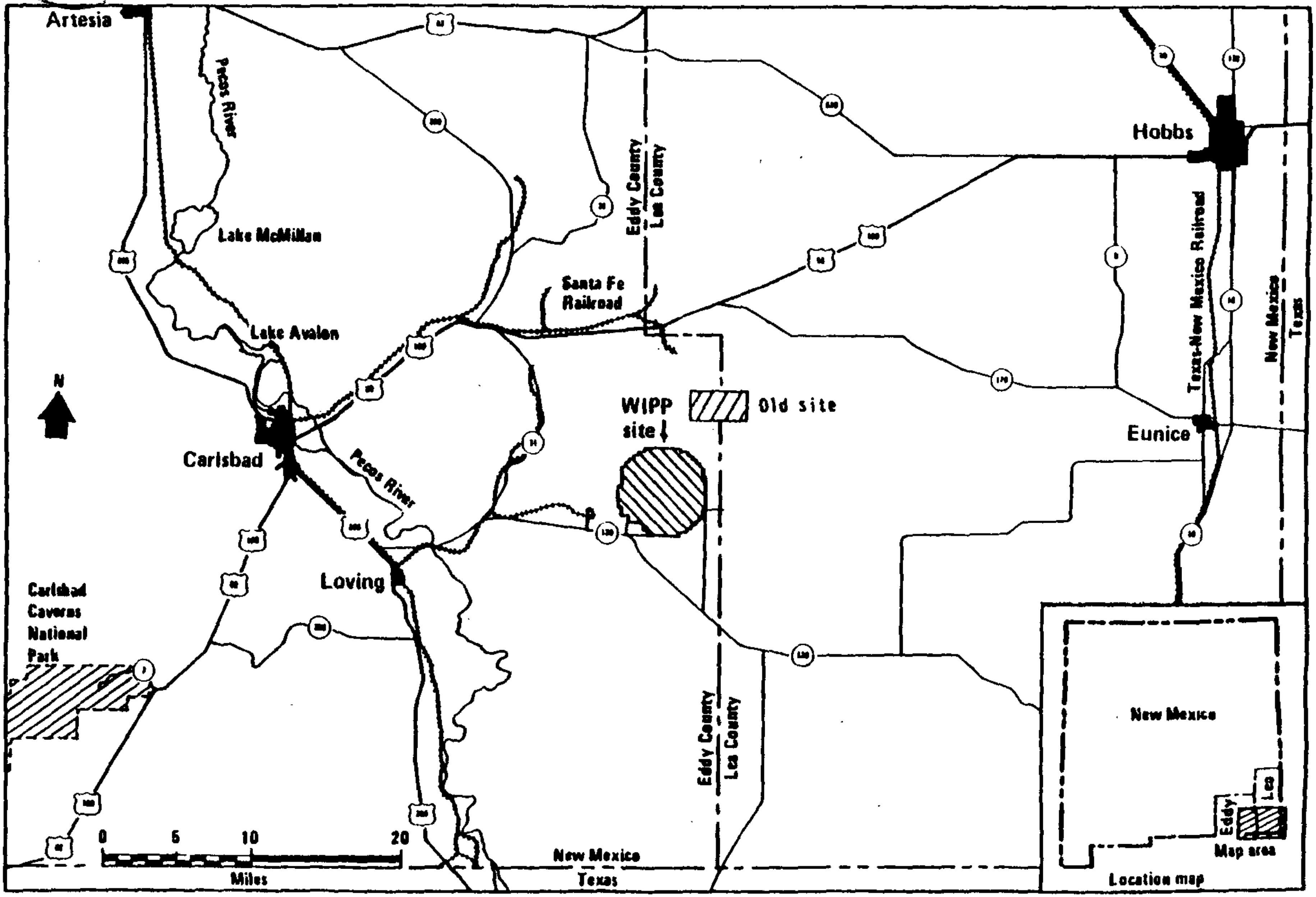
INTRODUCTION AND BACKGROUND

The history of the Waste Isolation Pilot Plant (WIPP) project was presented to this panel at a study planning session on June 5, 1978. As early as March 1974, the Oak Ridge National Laboratory had begun to look for an underground terminal radioactive waste repository for commercial high-level waste in a region selected by the U.S. Geological Survey (USGS) in the Los Medanos area of New Mexico. In May of that same year, this search was suspended in favor of the concept of retrievable surface storage, and the land-withdrawal action that had been initiated was deferred in December 1974.

The Albuquerque Operations Office of the U.S. Atomic Energy Commission (AEC) and the Sandia National Laboratories were then requested by AEC headquarters to become involved in the program to locate a site for a radioactive waste disposal pilot plant for defense-related transuranic (TRU) waste, with some provisions for experimentation with defense high-level waste. When drilling began in 1975 at a site in the Los Medanos region recommended by Sandia, irregular subsurface geological conditions were found, including high-pressure brines and gases. Consequently, the first site was rejected, and a new one was identified independently by Sandia and USGS 11.2 km to the southwest. The general location of the site and a geologic section through the Los Medanos area are shown in Figures 1-1 and 1-2, respectively. In January 1976 the geological investigations were resumed at the newly proposed site, and the project was given its present name: Waste Isolation Pilot Plant.

The drilling of ERDA-9, the first hole at the new site, commenced in April 1976. In October 1976, funding was requested for an architect-engineer, and a new land-withdrawal notice was placed in the Federal Register in December 1976. In April 1977 a preliminary version of the Draft Environmental Impact Statement was distributed by the U.S. Department of Energy (DOE) for comment, and it was announced that WIPP would be a licensed facility. In June the final version of the conceptual design was issued. In September, Bechtel was selected as the architect-engineer, and in November the DOE sent a letter to the U.S. Nuclear Regulatory Commission saying it intended to request a license.

In February 1978 the "Deutch Report" (U.S. Department of Energy 1978) called for a demonstration of the experimental emplacement of



FI( ) 1-1 General location of the WIPP site. Sour U.S. Department of Energy (1980).

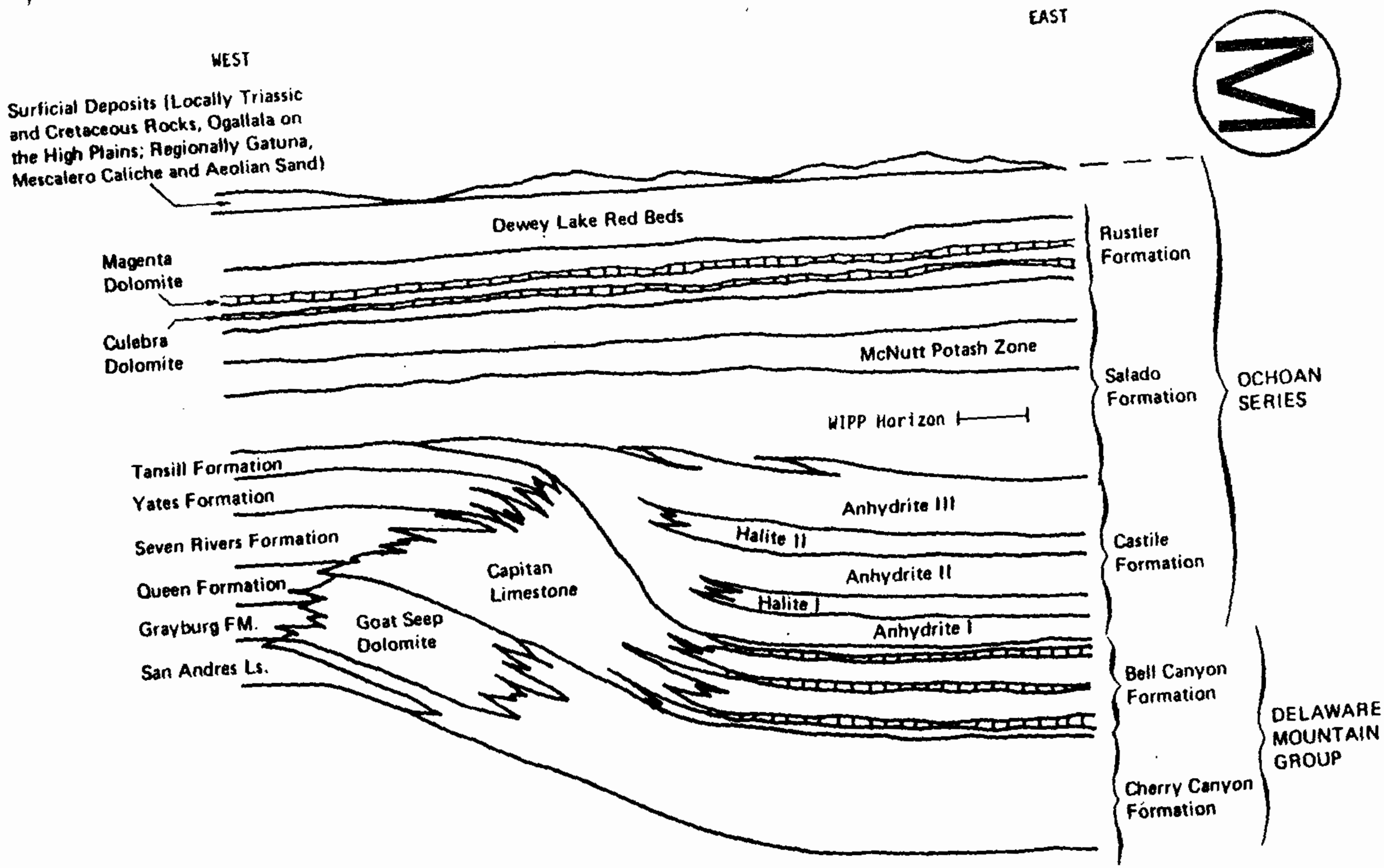


FIGURE 1-2 Diagrammatic section showing stratigraphy of the Delaware Basin. Not to scale.
Source: Lambert (1983).

high-level waste and possibly ultimate disposal of commercial spent fuel at the WIPP site. Objections were raised by the Committee on Armed Services of the U.S. House of Representatives, which insisted that the site should be unlicensed and used only for defense waste. This view eventually prevailed.

The Geological Characterization Report (Powers et al. 1978), a compilation of geotechnical information available as of August 1978 and judged to be relevant to WIPP studies, was published in December 1978.

In March 1979 an Interagency Review Group (IRG) appointed by President Carter reported on its review of the progress of the U.S. waste disposal program and suggested four alternative technical strategies, one of which would specify salt as the host geologic medium for the first mined repository (Interagency Review Group 1979). The following month, DOE issued for public comment the WIPP Draft Environmental Impact Statement, or DEIS (U.S. Department of Energy 1979), including consideration of the possibility of disposal of limited quantities of commercial spent fuel.

Public Law 96-164, enacted in December 1979, authorized WIPP as a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the U.S. Nuclear Regulatory Commission. Within three months, President Carter announced his intention to recommend cancellation of WIPP and requested rescission of previously appropriated funds. Congress did not act on the rescission request, however, and the project continued, as authorized by PL 96-164.

The WIPP Safety Analysis Report, or SAR (U.S. Department of Energy 1980-1983), was issued in February 1980 and has been updated by amendments in September 1980, January and October 1981, September 1982, and January and March 1983.

In October 1980 DOE issued a Final Environmental Impact Statement, or FEIS (U.S. Department of Energy 1980), which included responses to comments received from the public and from government agencies and which reflected changing policies and legislative requirements. In this document the concept of an intermediate-scale facility for the disposal of spent fuel and the associated two-level underground layout were eliminated from the DEIS. Congressional action eliminated the proposal for licensing of the repository. Now, in view of further changes in WIPP plans as a result of efforts such as the cost reduction proposals mentioned below, this FEIS needs to be updated.

As of this writing, the WIPP repository is intended as an unlicensed facility for the disposal of TRU waste generated in U.S. defense programs and for the experimental emplacement and removal of a small quantity of high-level defense waste. No permanent disposal of high-level waste is planned. TRU waste, it should be noted, differs from high-level waste in that much less heat is generated. Calculations indicate that the maximum temperature rise in the center of the repository will be less than 2°C, a temperature rise that should cause negligible effects of heating the salt beds.

One of the first official acts of the Reagan administration was the January 1981 issuance of a Record of Decision to proceed with the project; but in April, the State of New Mexico filed suit against DOE to require acquisition of extensive additional technical information and the resolution of a number of controversial issues. Under the resulting Stipulated Agreement, signed in July 1981, a number of technical reports have been prepared by DOE and its contractors and examined by the panel.

In July 1982 DOE proposed simplification and reduction in scope of the WIPP facility and evaluated (U.S. Department of Energy 1982) the environmental consequences that might result from this cost reduction program. These were matters of particular interest to the panel and were the topics of several technical briefings.

A decision to "proceed with full facility construction" was announced by DOE in June 1983, following reports (U.S. Department of Energy 1983a,b) on the results of the recently completed Site and Preliminary Design Validation (SPDV) Program.

Independently of the current DOE-sponsored study by the National Research Council, the State of New Mexico itself has set up four groups concerned with WIPP--an Environmental Evaluation Group (EEG); a Radioactive Waste Consultation Task Force, composed of three members of the governor's cabinet; a Radioactive Materials Committee, composed of eight members of the state legislature; and, until June 1, 1981, a Governor's Advisory Committee on WIPP.

In addition to issuing a number of technical reports, the EEG has organized several conferences and field trips in which panel members have participated.

Waste Isolation Pilot Plant program activities were in progress during the course of this study; thus the panel was evaluating existing data and concepts while new information was being obtained and analyzed. This report is not a summary of WIPP activities, but an analytical commentary on certain aspects of those activities, as specified in the panel's charge stated in the Preface. For completeness, some material has been included that was incorporated originally in three special reports that dealt with site suitability of the proposed site near Carlsbad, New Mexico, from a geological and hydrological standpoint (see Appendix A); the limitations of surface exploration of underground formations (see Appendix B); and continued evaluation of the Carlsbad site (see Appendix C). An interim report (National Research Council 1983) on the first three years of this study has also been drawn upon, as appropriate.

CHAPTER TWO

SITE SELECTION AND CHARACTERIZATION

HISTORY

The criteria that were used in selecting the WIPP site reflect the criteria commonly cited in proposals for waste isolation in bedded salt (National Research Council 1970) and the geological criteria for repositories (National Research Council 1978) and seem technically and scientifically adequate. The recommendations include (1) a bed of rock salt (halite) at least 60 m thick, of purity sufficient to minimize chemical complications from brine of complex composition and from water released from hydrous minerals; (2) a depth greater than 300 m to ensure freedom from surface influences; (3) a depth less than 1,000 m to ensure acceptably low creep rates in the salt; (4) approximate horizontality to minimize difficulty in mining operations; (5) little indication of recent tectonic or igneous activity; (6) sufficient distance from an exposed edge or underground aquifer where salt dissolution is occurring; and (7) an area without a history of resource extraction and lacking sizable economic resources. Although other sites in the United States may also satisfy these criteria, a site in southeastern New Mexico was chosen, as described in Chapter 1.

Two additional criteria specific to the Carlsbad area were suggested by the conclusions of a study (Bradshaw and McClain 1971) at Lyons, Kansas, and by observations at an earlier WIPP site (a site near borehole ERDA-6): The repository should be located at least 1.6 km from the nearest borehole penetrating through the salt beds to avoid possible entry of surface water and at least 8 km from the Capitan Reef to avoid a zone of disturbed bedding known to parallel the reef (the "deformation front" on Figure 2-1).

With these criteria in mind, lines were drawn on a map to outline areas where salt beds of requisite thickness at proper depths were known to occur and to exclude areas within 1.6 km of known deep boreholes, within 8 km of the Capitan Reef, within 1.6 km of the dissolution edge, or with known potash or hydrocarbon resources. Two areas of reasonable size outside these lines were identified (see Figure 2-1). Site 2 had the disadvantages of deeper salt beds and closeness to an oil field where water flooding may be used for secondary recovery in the future. Thus, Site 1 seemed more suitable even though it was closer to the reef

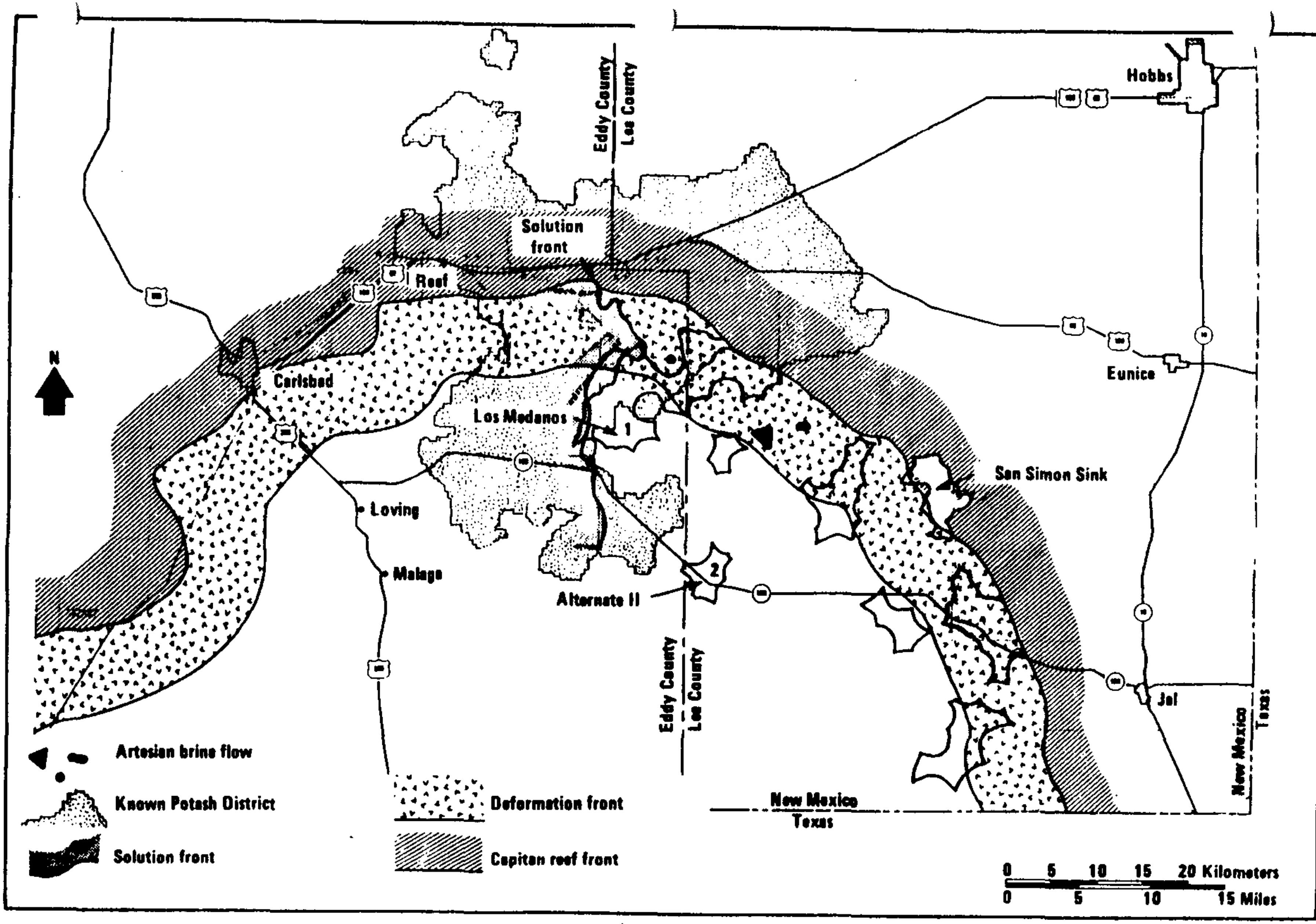


FIGURE 2-1 Application of the site-selection criteria. Source: U.S. Department of Energy (1980).

and the potash zone. The major regional geologic structures in the vicinity are shown in Figure 2-2, and a geologic section in Figure 2-3.

Site 1 was chosen and an exploratory shaft was constructed. The part of the Salado Formation preselected for repository construction was studied and logged in great detail where exposed to view in the shaft. For the shaft station a stratigraphic position was picked in a thick layer of halite containing only minor polyhalite, anhydrite, and a few thin clay seams. This precise position was chosen during a technical discussion among experts from DOE and its principal contractors; personnel of the USGS and EEG were kept informed, and their comments were solicited (Jarolimek and McKinney 1982).

REMAINING UNCERTAINTIES

Although the generic criteria as applied to the WIPP site are in large measure satisfied, questions have been raised about the suitability of the site to satisfy a few of the criteria in detail. Grounds for these questions include (1) the likely presence of economically significant quantities of potash and natural gas at the site; (2) possible tectonic instability of the site; (3) possible continued movement of the kind that produced the distorted structures in the evaporite beds of the "deformation front," ultimately affecting the now undisturbed beds in the middle of the WIPP site; (4) possible disturbance of the site by karst-forming processes; (5) possible local collapse of the salt beds as a result of solutions moving up from aquifers beneath the salt beds, leading to formation of vertical chimneylike masses of breccia (so-called breccia pipes); (6) possible interstratal ("strata-bound") dissolution of salt adjacent to layers of fractured or brecciated anhydrite, especially near the Castile-Salado contact, supposedly rapid during the late Cenozoic and continuing today; and (7) possible presence of pressurized-brine reservoirs.

These objections to the WIPP site have been expressed a number of times over the past several years. Some of the objections have been partially answered by recent work and so have become less serious, but valid questions remain about a few. The following discussion is focused on recent attempts to deal with these remaining questions.

Natural Resources

Further study after the site had been picked showed that probable potash resources, located in a zone 126 m to 240 m above the planned repository horizon, were greater than had been thought originally. The amount of possible hydrocarbon resources in strata below the salt beds was estimated during the study. Because of these resources, the ability of the site to satisfy the criterion relating to natural resource potential seemed dubious, and for a time this question loomed as a major flaw in the case for site suitability. A recent study indicates, however, that most current techniques of mineral exploitation can be safely employed in the outer part of the original site area (the former Zone IV, shown

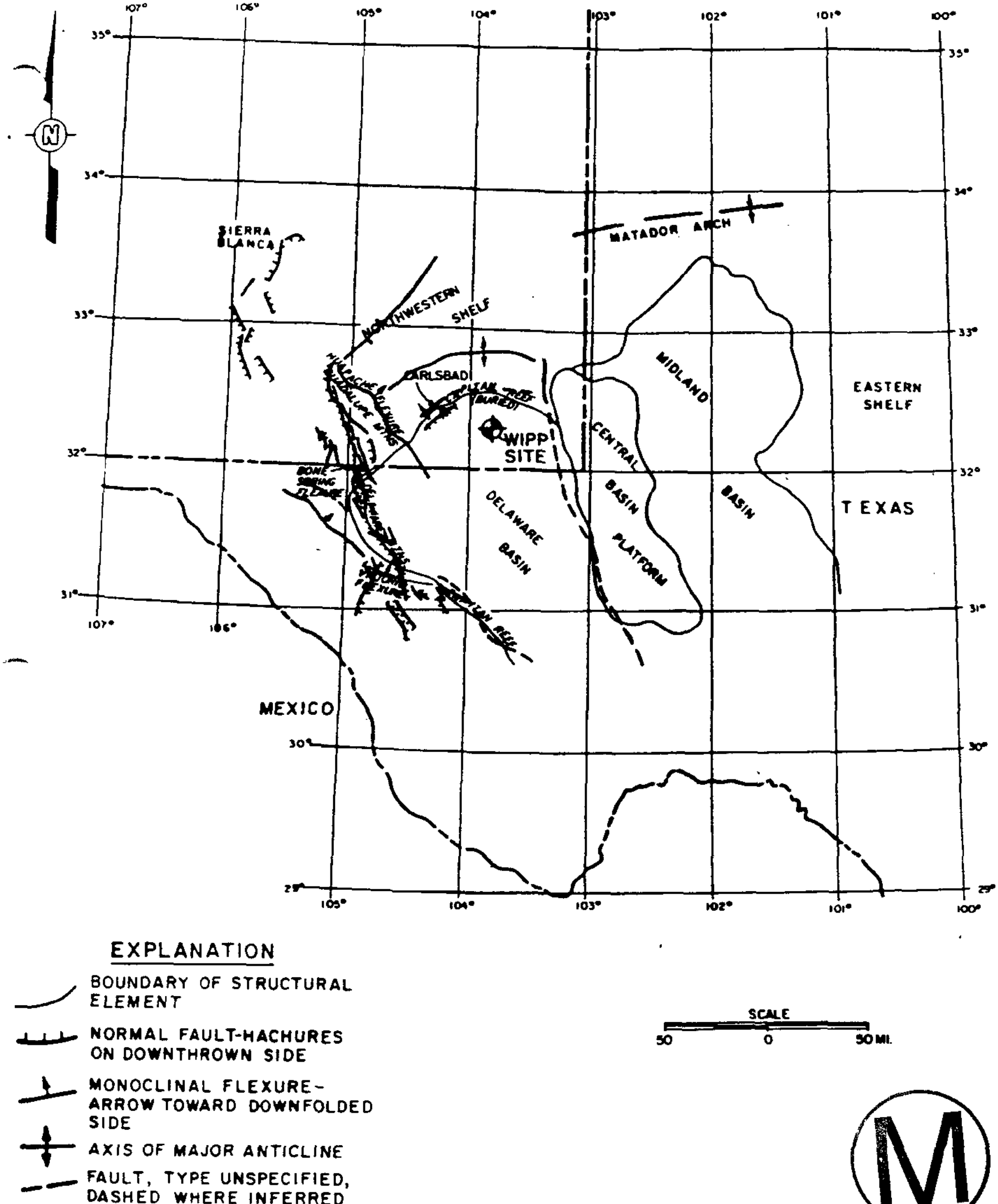


FIGURE 2-2 Major regional structures. Source: After Popielak et al. (1983).

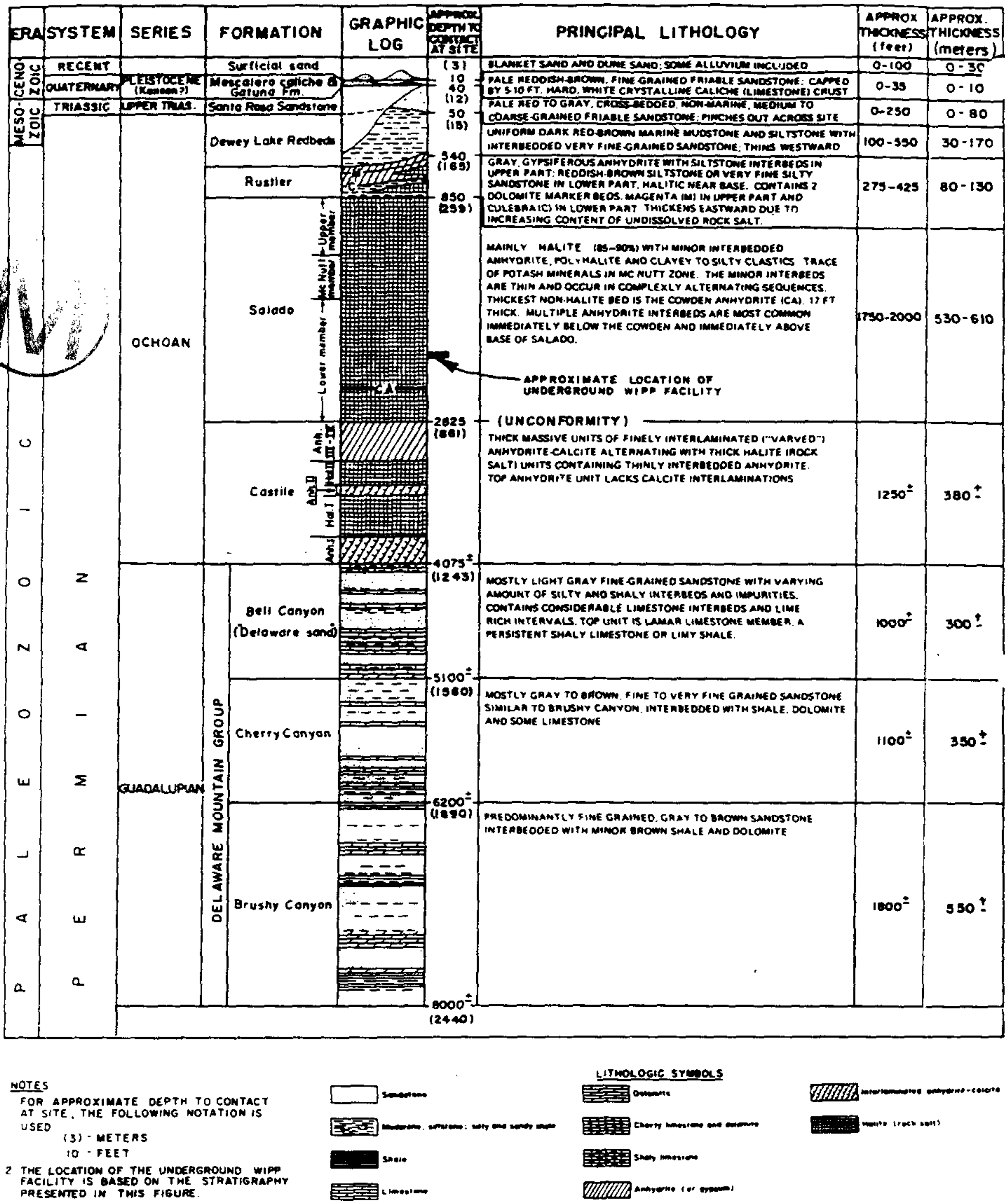


FIGURE 2-3 Geologic section at WIPP site. Source: After Popielak et al. (1983).

in Figure 2-4) (Brausch et al. 1982), so that a large part of the hydrocarbon and potash resources may be recoverable with no hazard to the waste facility. The main concern would be a disruption of water flow in the Rustler Formation, leading to possible reduced travel time to the Pecos River; but the analysis of Brausch et al. (1982) indicates that consequences would not be serious as long as exploitation is confined to Zone IV. The panel accepts this conclusion with the proviso that each proposal to develop the resources should be carefully examined, with the burden of proof as to its safety made the responsibility of the proposer.

More detailed discussion of the value of natural resources and the consequences of mining them is included in Appendix D.

Tectonic Stability

The well-known occurrence of fault displacements and basaltic eruptions during the Quaternary epoch in the Rio Grande Valley 250 km west of the site has been cited as indicating a possible risk of future tectonic disturbance at the waste facility. The risk is not wholly negligible, of course, but in the panel's opinion the long distance from the Rio Grande and from other areas of recent fault displacement, coupled with complete absence of seismic evidence for significant crustal movement and of geologic evidence for recent tectonic disturbance or volcanic activity, has seemed sufficient to assure long-term tectonic quiescence at the site. A seismic network established near the site has recorded nothing but minor tremors, most of them explicable by oil field flooding related to secondary recovery efforts along the Central Basin Platform to the east (Figure 2-2).

The "Deformation Front"

The "deformation front" is an area adjacent to the Capitan Reef in the northern and eastern parts of the Delaware Basin (Figure 2-1) in which evaporite beds are deformed, as shown by borehole data and seismic profiles. The deformed beds are in part strongly tilted, folded, and faulted, and in places show marked increases and decreases of their normal thickness. In general, the intensity of deformation decreases away from the Capitan Reef, and at the distance of the WIPP site is very slight. Deformed rocks at the margin of the disturbed zone have been encountered in boreholes in the northern part of the WIPP area, and stronger deformation is found beyond its borders to the northeast. In addition to the disturbed zone, small isolated areas of somewhat deformed rocks have been noted elsewhere in the basin, but none within 4 km of the WIPP site.

Concern has been expressed about the possibility that deformation may be continuing today and may affect the currently almost undisturbed strata in the middle of the WIPP site at some time in the future. Strong movements in the beds containing a waste facility, it is feared,

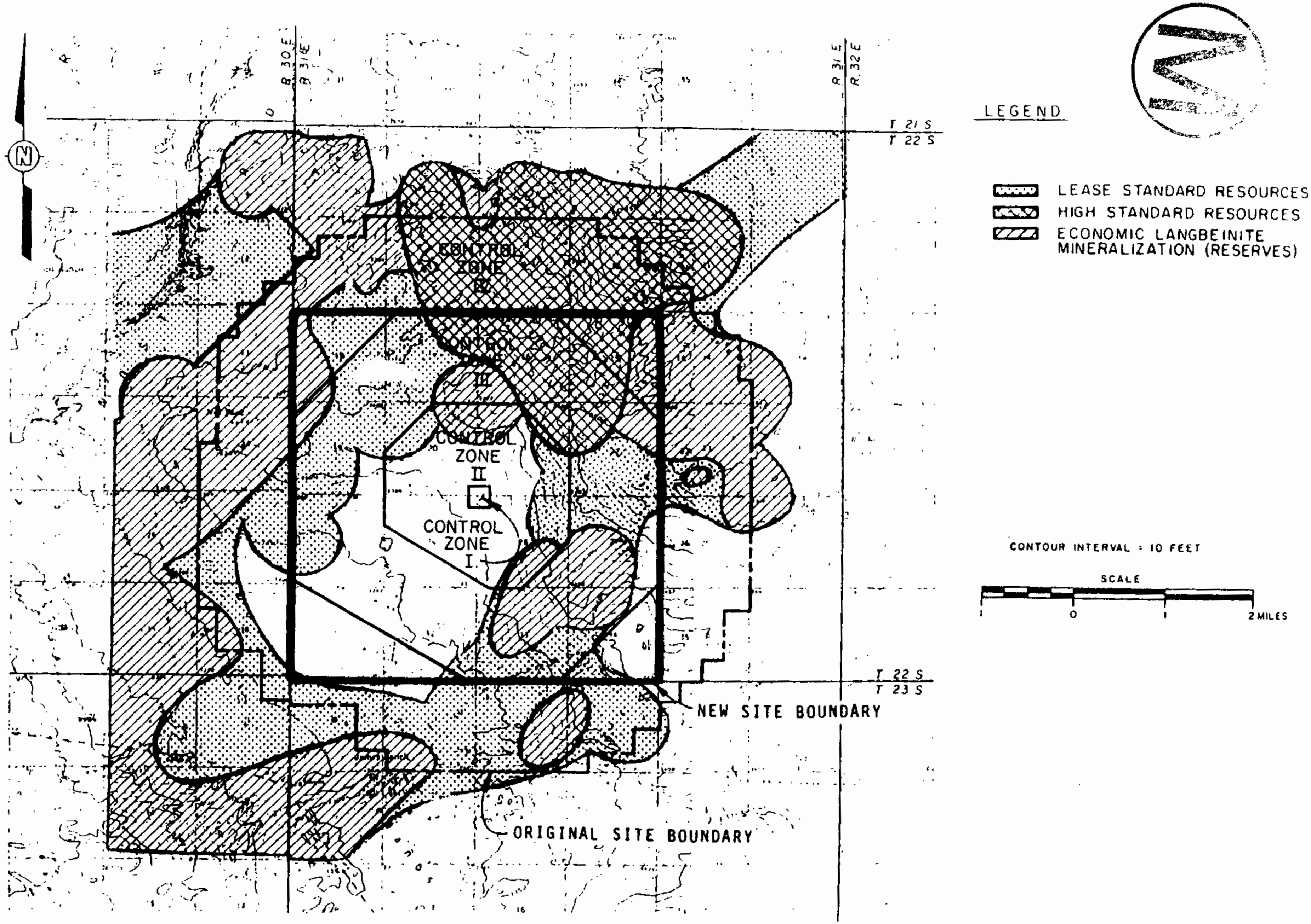


FIGURE 2-4 New control zone boundary and potash deposits at the WIPP site. Source: After Brausch et al (1982).

might disrupt the stored waste and permit entry of solutions that could dissolve and transport some of the radioactive material.

To investigate this possibility, an intensive study of deformation processes in the salt beds was carried out (Borns et al. 1983). The study includes detailed descriptions of the kinds of deformation present, evidence regarding the age of deformation, and discussion of several hypotheses of origin. Although the authors concluded that evidence is insufficient to give a firm date for the time (or times) of deformation episodes or to establish beyond question the mechanism by which the deformation occurred, they noted that by any reasonable hypothesis of origin, the time involved in forming the observed structures is very long, at least many tens of thousands of years. Hence the deformation, even if it is continuing now, would not "present a major hazard to the construction and operational stages of the facility."

Karst-forming Processes

The Los Medanos region, like other areas of the world underlain by soluble rocks, is subject to locally rapid (meaning times of the order of thousands of years) and potentially widespread dissolution wherever undersaturated solutions come in contact with the rocks beneath. Some of the dissolution may be due to water working down from the surface and some to groundwater moving through permeable beds and channels below the surface. As parts of the rock dissolve, overlying material collapses into the open spaces. The result is a distinctive kind of topography called karst, characterized by sinkholes, caves, valleys without stream channels, and underground drainage (Bachman 1980, p. 46)--features prominently displayed in parts of southeastern New Mexico near the WIPP site. Although no karst features have been noted at the site itself, the presence of such features within several kilometers, particularly in Nash Draw (about 10 km west of the site), has led to concern that karst may work its way into the site in the near geologic future and provide pathways for water to reach a subsurface waste facility.

Dissolution is undoubtedly in progress on the buried uptilted edges of the evaporite beds in the western part of the Delaware Basin, and can be expected to work its way slowly eastward. Important questions, then, relate to the rate of present dissolution, the predictability of this rate, and possible future changes in the rate due to climatic change or tectonic disturbance.

The rate of dissolution has been estimated in various ways. In Nash Draw, where geologically recent dissolution has removed much of the Rustler Formation and part of the upper Salado, two Pleistocene formations, the Gatuna and the Mescalero, in part lie undisturbed on an old karst surface and in part have collapsed as a result of continuing dissolution. From these, facts Bachman (1980) concluded that present karst features have formed during and since the deposition of these beds. The older one (Gatuna) can be confidently dated, from potassium-argon dating of an included bed of volcanic ash, as about 600,000 years old. From the thickness of evaporite strata removed since

Gatuna deposition, Bachman derives an average rate of vertical dissolution of 10 cm in 1,000 years. A similar figure has been estimated from the amount of salt currently being dissolved and discharged by streams and springs in the basin (U.S. Department of Energy 1980, p. 7-98). For the rate of advance of horizontal dissolution, Bachman and Johnson (1973) estimated 10 to 13 km per million years, on the assumption that "at the end of Ogallala time the Salado Formation extended to the Capitan Reef on the western edge of the basin." These estimates suggest that a waste facility at the WIPP site should be secure from karst-forming processes for at least a million years.

Implicit in this conclusion is the assumption that the future climate of southeastern New Mexico will be similar to the average climate over the past 600,000 years. During this period in the past, the climate has fluctuated from arid to pluvial, but on the whole has been fairly arid. Average climates in the future probably will not deviate greatly from this pattern (Bachman 1980); nor is it likely, as noted in the previous section, that tectonic movement in the next few hundred thousand years will elevate this region sufficiently to cause a marked change in average rainfall.

The panel recognizes that estimates of dissolution rates and guesses about future climates are based on somewhat slender evidence, but the assumptions involved are reasonably conservative, and the general conclusion that a repository at the WIPP site would not be disturbed by karst-forming processes for a million years or more seems well founded.

Breccia Pipes

The possibility of the formation of vertical pipelike masses of breccia by collapse induced by solutions working their way upward into the repository in the salt beds from aquifers beneath, similar to breccia pipes observed elsewhere in the basin, has been raised repeatedly over the past several years (Anderson and Kirkland 1980, Anderson 1981a,b). An early form of this hypothesis envisioned solutions in the Bell Canyon Formation (of the Delaware Mountain Group below the evaporite beds) as the active agents of dissolution and postulated that the solutions not only formed the collapse pipes, but also worked their way along the Castile-Salado contact, dissolving the lower Salado salt (in which the repository would be sited) as they moved. In other words, a combination of the fifth and sixth uncertainties mentioned previously was proposed--active formation of breccia pipes and widespread dissolution of salt in the lower Salado, in part by solutions rising into the pipes from below.

More recently, the formation of breccia pipes near the waste facility has been shown to be highly improbable (Wood et al. 1982, Lambert 1983), and none has been encountered during SPDV excavation activities. The demonstration that formation of breccia pipes poses no appreciable hazard to the WIPP site depends on a recent theoretical argument and additional field data. Until recently, the formation of breccia pipes has been attributed to a mechanism of "brine density flow"--the rise of unsaturated solutions into overlying salt beds, the dissolving of salt to form more concentrated and hence more dense solutions, and the descent of these dense solutions to make room for fresh injections of unsaturated fluid (Anderson and Kirkland 1980). On theoretical grounds, this mechanism could produce pipes of collapsed material only if dissolution at the base of the salt section were fairly rapid. With fast-enough dissolving of salt, a cavity or zone of weakness might be produced into which overlying beds would collapse by brittle fracture; but if the dissolving were slow, the salt would gradually subside by plastic flow to form a funnel-shaped volume of somewhat deformed beds rather than a pipe of brecciated salt (Davies 1983c).

Sufficiently rapid dissolution for producing a pipe at the WIPP site could only be caused by fluids in the Bell Canyon Formation, which underlies the salt. Recent data on this formation, however, indicate that it is not a credible source of such fluids. The permeability of this formation is currently in dispute (Davies 1983a, Lambert 1983), but even the higher of the proposed values would supply insufficient water for breccia pipe formation by the brine-density flow mechanism (Neill et al. 1983, p. 8; L. Chaturvedi, New Mexico Environmental Evaluation Group, personal communication, 1983). An additional argument against the efficacy of water from the Bell Canyon Formation has been advanced by Spiegler (1982): using reasonable numbers for the properties of salt and solutions in the Bell Canyon, he calculated that the rate of plastic flow of salt would be on the order of a hundred times its rate of removal by dissolution, so that possible channels leading to breccia pipes could not remain open. Still another argument is the simple fact that the Bell Canyon Formation does not extend under any of the known breccia pipes.

A more likely cause of breccia pipes is sudden collapse into an opening dissolved out of an underlying brittle rock such as limestone. All known pipes in the Los Medanos area have been shown to exist only in places where the salt beds overlie parts of the limestone of the Capitan Reef; and the near certainty that collapse originated in the limestone has been established by deep drilling in one of the pipes that showed breccia persisting downward to the bottom of the drill hole, presumably only a few meters above the reef (Snyder and Gard 1982).

Since the WIPP site is 8 km from the nearest part of the reef, and since solutions in the Bell Canyon Formation are unlikely to cause sudden collapse in the salt itself, the formerly suggested danger of encountering an old pipe at the WIPP site, or of a pipe forming anew under the waste facility, seems remote. More details on breccia pipes are found in Appendix E.

Deep Interstratal Dissolution

Anderson (1982a) has continued to express concern about possible extensive deep interstratal dissolution caused by solutions generated by infiltration of meteoric water, moving long distances through layers of fractured anhydrite near the Castile-Salado contact and dissolving halite from the beds above and below. The evidence for such dissolution is chiefly the absence of much of the lower Salado salt under the western part of the basin (Anderson et al. 1972, Anderson 1981b, 1982a). The amount of missing salt was estimated by extrapolating salt thicknesses from areas where salt is believed to be intact to areas where salt is thinned or missing. Detailed matching of fine laminations ("varves") in the evaporite sequence, particularly in anhydrite beds, in cores from drill holes at intervals across the site, suggested an assumption that Salado salt was originally deposited throughout the Delaware Basin. The gap in the salt sequence supposedly is due to dissolution; the anhydrite breccias ("dissolution breccias" formed as residues of salt dissolution) in some of the cores from the western half of the basin are cited as further evidence. Some of the surface depressions above the supposed dissolution front, according to this hypothesis, were formed by subsidence due to dissolving out of salt beneath; from the fact that sediments near the surface in these depressions are no older than Pleistocene, Anderson has concluded that rapid dissolution is limited to the past few million years and is probably continuing today. Water for dissolving the salt is assumed to be of meteoric origin (Anderson 1982a). It descends into the upturned salt edge in the western part of the basin, traverses layers of fractured and brecciated anhydrite near the Castile-Salado contact, and leaves the basin through cavities in the buried Capitan Reef on the east side. The brine reservoirs encountered in the ERDA-6 and WIPP-12 drill holes are cited as ponded remnants of the solutions that have moved, or are moving, through the brecciated anhydrite layers.

The validity of this hypothesis is difficult to judge against alternative ideas. Scientists at Sandia National Laboratories have agreed that strata-bound dissolution of the sort described above is possible and may well be responsible for formation of some of the surface depressions in the Los Medanos area (Lambert 1983). They disagreed with regard to the scale and recency of the dissolution process. The earlier hypothesis envisions solutions moving completely through the evaporite basin to the Capitan Reef, concentrated in strata near the Castile-Salado boundary, and active primarily in the last few million years. By contrast, the Sandia scientists considered strata-bound dissolution to be a relatively minor process today and in the recent geologic past; they regarded it rather as a phenomenon that was active adjacent to many anhydrite beds at various times since the Permian, is restricted to the western part of the basin, and is limited in its range by escape of the solutions into various debris-filled depressions. According to the earlier hypothesis, the dissolution is active enough and extensive enough to be a serious threat to a waste facility at the WIPP site; to the Sandia scientists, the interstratal dissolution is simply a minor part of the slow, general dissolution of the evaporite sequence that has gone on intermittently for hundreds of millions of years and poses no appreciable hazard to the proposed facility.

An example of a structure that may have been formed by deep interstratal dissolution has been pointed out by Davies (1983a). This is the so-called FC-92 depression, an area 2 km north of the WIPP site where geophysical data indicate a pronounced funnel-shaped subsidence depression in Salado beds. The subsidence could be the result of slow dissolution by fluid moving upward from the Bell Canyon Formation or from flow along an anhydrite stratum in either the Castile or lower Salado. Modeling by Sandia scientists (A. Lappin, Sandia National Laboratories, personal communication, 1983) has shown that subsidence due to fluid from the Bell Canyon Formation is unlikely because the amount of subsidence would require greater groundwater flow in the Bell Canyon than can be postulated even with the most generous assumptions about permeability. The origin of the depression remains uncertain: it cannot have formed by dissolution over a period of a few million years by Bell Canyon fluids, but it does provide a possible indication of dissolution by some sort of deep interstratal solution at some time in the past, perhaps by undersaturated brine moving along an anhydrite bed well above the Bell Canyon.

Thus, the question of the extent and timing of deep dissolution is still unsettled. In one hypothesis, dissolution is extensive, largely limited to the last few million years, and probably still active; in the other hypothesis, dissolution is very slow and has been in progress for most of the last 200 million years. In the panel's opinion, the preponderance of evidence favors the second, but the evidence is not conclusive. A choice between the two viewpoints depends on answers to two questions: (1) Can actual movement of large volumes of fluid through anhydrite beds near or below the Castile-Salado contact be demonstrated, either as present-day movement or movement in the recent geologic past? and (2) Is there evidence for major dissolution only in the late Cenozoic, as opposed to dissolution at intervals since the Permian?

Movement of Fluid Through Anhydrite

Brine reservoirs like those encountered in Castile anhydrites in the ERDA-6 and WIPP-12 boreholes were regarded by Anderson (1982b) as prime evidence for his hypothesis. The brine reservoirs, in his view, are isolated pockets containing samples of the solutions that have moved or perhaps are moving through the anhydrite layers. As a source for the dissolution fluids, he has suggested either rainfall in an area of gravels near the west margin of the Delaware Basin (Black River gravels) or water from the Pecos River where it crosses the uptilted Salado-Castile contact; as a sink for the solutions, he proposes the cavernous Capitan Reef limestone on the east and northeast sides of the basin. Lambert (1983) argued, on the other hand, that analysis of the brines in the reservoirs shows that they cannot be the result of simple dissolution of halite, because neither the observed chemical composition nor isotopic composition is compatible with such a process. He pointed out also that fractured anhydrite lacks some expected characteristics of a dissolution breccia (no concentration of residual clay minerals and none of the gypsum that should form if water-filled open spaces develop in anhydrite) and is more likely produced by deformation of the salt beds. The brine reservoirs he regarded as pockets of brecciated material created by slight movement in the salt layers near the edge of the "disturbed zone" adjoining the Capitan Reef; the brine has accumulated from a variety of sources, perhaps partly from fluids that traveled through once-permeable portions of the Castile and partly by "kneading out" of fluids (Borns et al. 1983) from halite beds during deformation, and remains immobile. The facts that the brine reservoirs have pressures well above hydrostatic, that flow of brine from one reservoir has no effect on nearby reservoirs, and that anhydrite recovered from most boreholes that penetrate this horizon is not fractured and contains no fluids, are good evidence that the reservoirs are not part of a widespread interconnected aquifer, at least not one that contains brine circulating at the present time.

As additional tests of Anderson's views, scientists at Sandia National Laboratories plan two kinds of study: the first making firmer estimates of the amount of salt deposited and removed by comparing in detail drill cores and borehole logs from many parts of the basin, and the second studying in detail the characteristics of residual breccias formed by dissolution in anhydrite beds, to establish criteria for distinguishing such breccias from similar fractured material produced by salt movement.

Dissolution Limited Chiefly to the Quaternary

Some dissolution of salt undoubtedly has taken place at various times since the Permian, but Anderson (1981a,b) has concluded that the major part is geologically recent and hence is probably active at present. This conclusion is based on two kinds of evidence: the supposed recency of the eastward tilting of beds in the Delaware Basin (late Tertiary), which triggered the dissolution, and the supposed lack of sediments older than Pleistocene in depressions whose origin is ascribed to dissolution of the salt beneath. The Sandia workers (D. W. Powers, Sandia National Laboratories, personal communication, 1982; Lambert 1983) have stated that the time of tilting of the evaporite beds is uncertain, but if it is part of the widespread disturbance that formed basin and range structures in the western states, it should be dated as mid-Tertiary rather than late Tertiary. They have pointed out also that little is actually known about the age of deposits in depressions in the Los Medanos area; certainly the depressions southeast of the WIPP site (the so-called Maley-Huffington troughs) contain Pleistocene sediments at the surface, but these sediments may conceal older beds beneath. Information about maximum age of the depression fills might be obtainable from boreholes drilled for this purpose, but datable material is probably so scarce in such sediments that definitive dating might require many boreholes, and it is uncertain whether the expense of such an enterprise would be justified. A clear decision about the timing of most salt dissolution seems impossible on the basis of currently available evidence. Further information on salt dissolution is found in Appendix F.

Because clear evidence for salt removal from the lower Salado is found no closer than 20 to 30 km south of the WIPP site itself, because evidence for major dissolution in the late Cenozoic rests on the questionable Quaternary age of the entire thickness of sedimentary fill in solution basins, and because the existence of a connection to an adequate sink for postulated dissolution brines of the present day is questionable, the panel doubts that deep dissolution, even if it is occurring as Anderson supposes, is progressing fast enough to jeopardize the integrity of a repository within the next million years.

Pressurized-Brine Reservoirs

Pressurized brine accompanied by carbon dioxide, methane, and hydrogen sulfide has been encountered in several wells penetrating the Castile Formation (Griswold 1980, Popielak et al. 1983). The brine occurs in fractured anhydrite in places where the salt beds are deformed, most of them in the zone of deformation near the Capitan Reef. An especially large brine pocket (estimated brine volume of 2.7×10^6 m^3) was encountered during the deepening of drill hole WIPP-12 in November 1981, only about a mile north of the center of the projected repository site, and this finding has led to concern that (1) the brine in this and other reservoirs may be part of an interconnected flow of brine through the anhydrite layer, and (2) a similar large reservoir may exist at or near the repository site and could cause flooding of the repository.

Investigation of the WIPP-12 occurrence, together with previous studies of other brine pockets, has shown that such concerns are without substance (Popielak et al. 1983). The principal lines of evidence are the following:

- In the Salado Formation, where the repository is to be constructed, no brine pockets have been found except fairly small ones (9.5 to 720 m^3) at low pressures (Griswold 1980).
- The chemical and isotopic composition of brines differs from resevoir to reservoir and is also different from the composition of groundwater in aquifers above and below the salt beds.
- Brine pockets can be emptied by allowing the brine to flow.
- Salt beds are undeformed at the repository site.
- Even if the reservoir found in WIPP-12 should extend under the repository site, or if another reservoir should exist at the site, the anhydrite layer is nearly 250 m below the proposed repository horizon in the Salado Formation.

On the basis of this evidence and observations made as part of the SPDV program, the panel concludes that brine reservoirs do not pose a threat to the integrity of a repository at the selected site.

SUMMARY

The panel believes that sufficient data exist to show that there is little appreciable hazard to a waste facility at the WIPP site from breccia pipes, tectonic disturbance, brine pockets, or extension of the "disturbed zone." If the hydrocarbon and potash resources at the site prove to be economically worth recovering, with proper limitations much of these resources can be recovered without hazard to the repository. The preponderance of evidence, in the panel's opinion, does not suppor Anderson's hypothesis of large-scale, recent strata-bound dissolution that might endanger a repository at the WIPP site, but the evidence against the hypothesis is not conclusive. Further evidence is obviously desirable, and the panel endorses the plans of Sandia National Laboratories to obtain firmer estimates of the amounts of salt deposited and removed by comparing drill cores and borehole logs from many parts of the basin, and to seek definitive evidence about water flow and dissolution residues in anhydrite beds.

CONCLUSIONS

o The presence of hydrocarbon and potash resources at the WIPP site is not a seriously adverse feature, because it should be feasible to recover much of the potash from the former Zone IV and the hydrocarbons from under the entire site by oblique drilling without harm to the repository. The effects of such extraction can be evaluated on a case-by-case basis (p. 11).

o Long-term tectonic quiescence at the WIPP site seems assured by its great distance from faults of recent displacement and areas of volcanic rocks, and by the lack of evidence of major seismic events nearby (p. 11).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it should not present a significant risk to the repository (pp. 11, 13).

o Evidence is good that, for a period of more than a million years, karst-forming processes are unlikely to expose the repository (pp. 13-14). Further studies will determine if the karst is likely to affect hydrologic transport in the site area.

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause breccia pipe formation indicates that the likelihood of encountering an old pipe or of a new one forming near the WIPP site is practically nonexistent (pp. 14-15; see also Appendix E).

o Evidence seems good that the trata below the salt beds (the Bell Canyon Formation) cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could they be responsible for extensive interstratal dissolution (pp. 15-17).

o The preponderance of evidence does not support the hypothesis that large-scale interstratal dissolution might endanger a repository at the WIPP site (pp. 16-19).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are isolated pockets of fluid not connected with or residual from solutions that have recently moved, or are moving for long distances through the formation (p. 19). Even if the pressurized-brine reservoir encountered in the WIPP-12 borehole in the Castile Formation were to extend directly beneath the WIPP site, this should not adversely affect the operating facility, and the existence of this reservoir is insufficient justification to stop the WIPP project.

RECOMMENDATIONS

o Each proposal to develop resources in the former Zone IV should be examined rigorously on a case-by-case basis, with the burden of proof as to its safety resting on the proposer. The U.S. Department of Energy should obtain the right to deny mineral extraction from the salt beds and hydrocarbon extraction from deep levels below the salt in the old Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 10-11).

o To test the extent of deep strata-bound dissolution, the plans of Sandia National Laboratories for further field and analytical work should be implemented (pp. 17-18).

CHAPTER THREE

IN-SITU TESTS AND EXPERIMENTS

THE WIPP R&D PROGRAM

The WIPP R&D program seeks answers to questions about repository development and waste package interactions, as shown in Figure 3-1 (Matalucci et al. 1982). This program consists of projects for verification of the various models, laboratory and field testing of components, and in-situ tests with and without radioactive material. The initial phase of the in-situ tests, termed Site and Preliminary Design Validation (SPDV), consisted of establishing baseline values of geomechanical properties in the early excavations (cf. Figure 5-2 for the SPDV area) and preliminary measurements of changes in these properties. As of October 1983, instruments had been installed and measurements had been made in the SPDV. Measurements will continue in the next phase of work, the in-situ experimental program.

A variety of in-situ experiments are planned for the WIPP R&D program (Figure 3-2) extending to the 1990s (Figure 3-3), to be carried out in a special area (Figure 3-4). Although planning for and design of the eventual construction and operation of the WIPP facility for permanent disposal of defense-generated transuranic (TRU) waste is already under way (U.S. Department of Energy 1980-1983) and discussions of its layout are in progress, the WIPP facility design is subject to change, depending on findings from the in-situ tests. Even the total abandonment of the WIPP site would be possible if the findings prove that permanent disposal of TRU waste is not feasible at the WIPP site. The panel regards WIPP facility planning and design to be subject to revision in the light of future findings of the WIPP R&D program. Therefore, the panel has directed its attention to the adequacy of the R&D program for providing the information needed to construct and to ensure the safety of the WIPP facility.

THE SPDV PHASE

Two underground shafts were available for in-situ testing in the SPDV program. These shafts, which were sunk in accordance with a previous recommendation by the panel (Appendix B), are 3.7 m and 1.8 m in

	TECHNICAL DEVELOPMENT			IN SITU TESTS WITHOUT RADIOACTIVITY			IN SITU TESTS WITH RADIOACTIVITY		
	MODEL DEVELOPMENT	LAB TESTING	FIELD TESTING	SPDV	TECHNOLOGY EXPS (TEs)	TECHNOLOGY DEMO	RADIATION-SOURCE EXPS (RSEs)	DHLW TESTS	TECHNOLOGY DEMO
SITE CHARACTERIZATION AND EVALUATION	●	●	●	●					
REPOSITORY DEVELOPMENT									
THERMAL/STRUCTURAL INTERACTIONS	●	●	●	●	●				
PLUGGING AND SEALING	●	●	●		●				
OPERATIONS		●	●			●			●
WASTE PACKAGE INTERACTIONS									
WASTE PACKAGE PERFORMANCE	●	●	●		●		●	●	
NEAR-FIELD EFFECTS	●	●	●		●		●		

FIGURE 3-1 WIPP R&D program. Source: Matalucci et al. (1982).

	WITHOUT RADIOACTIVITY			WITH RADIOACTIVITY		
	SPDV	TECHNOLOGY EXPERIMENTS	DEMONSTRATIONS	RADIATION-SOURCE EXPERIMENTS (OPTIONAL)	DHLW TESTS	DEMONSTRATIONS
SITE CHARACTERIZATION AND EVALUATION	• SITE VALIDATION INVESTIGATION					
REPOSITORY DEVELOPMENT						
THERMAL/STRUCTURAL INTERACTIONS	• PRELIMINARY DESIGN VALIDATION	• 12 W/m² MOCKUP • DHLW OVERTEST • GEOMECHANICAL EVALUATION • HEATED AXISYMMETRIC PILLAR • IN SITU STRESS FIELD • DIRECT SHEAR OF CLAY SEAM				
PLUGGING AND SEALING		• PERMEABILITY MEASUREMENTS • SIZE EFFECTS • PLUG TEST MATRIX				
OPERATIONS			• MOCK DHLW EMPLACEMENT AND RETRIEVAL • MOCK TRU WASTE HANDLING			• SMALL-SCALE TRU WASTE (OPTIONAL) • FULL-SCALE TRU WASTE DISPOSAL • DHLW EMPLACEMENT AND RETRIEVAL
WASTE PACKAGE INTERACTIONS						
WASTE PACKAGE PERFORMANCE		• SIMULATED-WASTE PACKAGE PERFORMANCE • SIMULATED-TRU-WASTE DRUM DURABILITY		• RADIOACTIVE-WASTE PACKAGE PERFORMANCE	• DHLW TESTS	
NEAR-FIELD EFFECTS		• BRINE MIGRATION (THERMAL)		• BRINE MIGRATION (THERMAL AND RADIATION)		

URE 3-2 WIPP in-situ tests. Source: Matalucci et al. (1982).

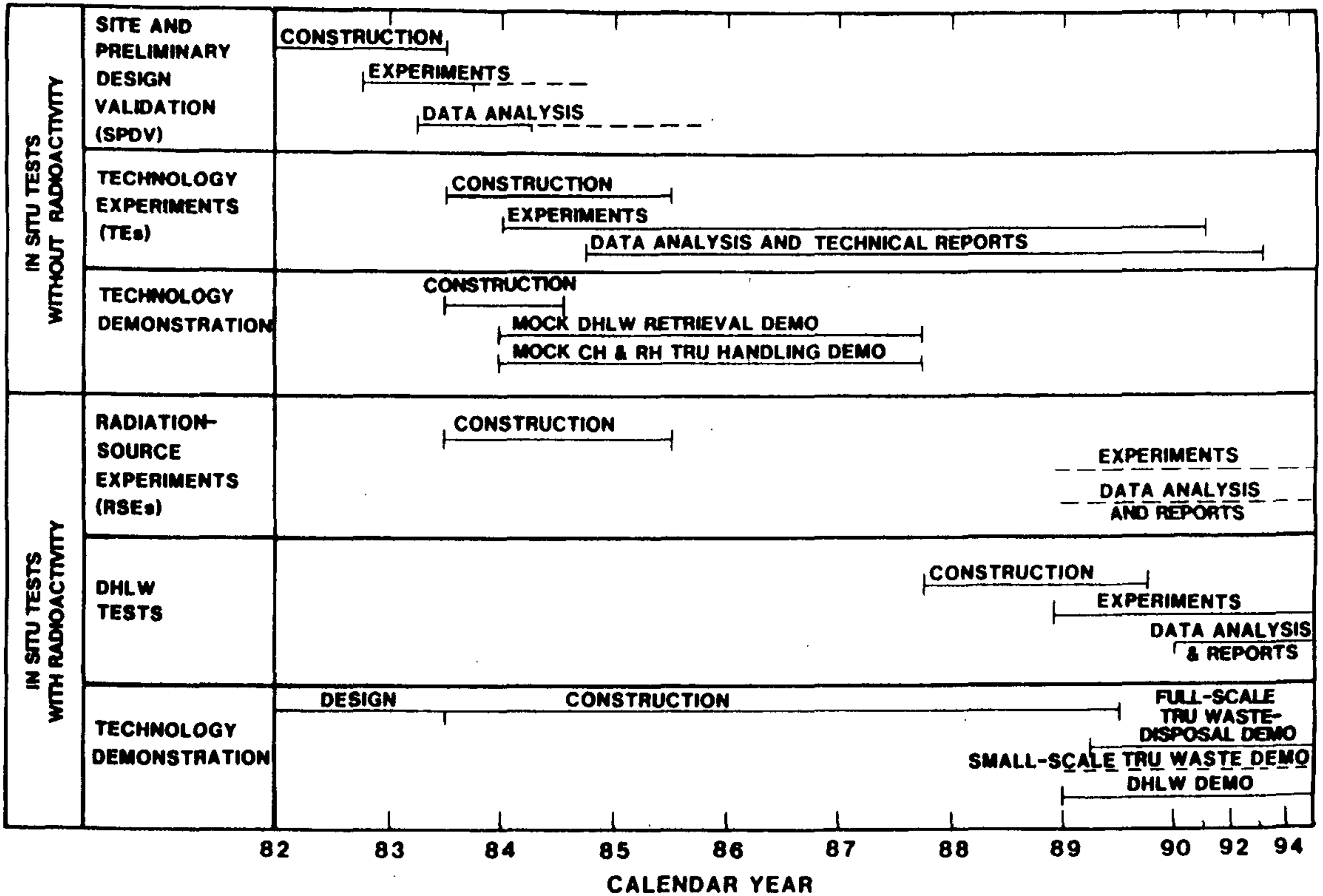
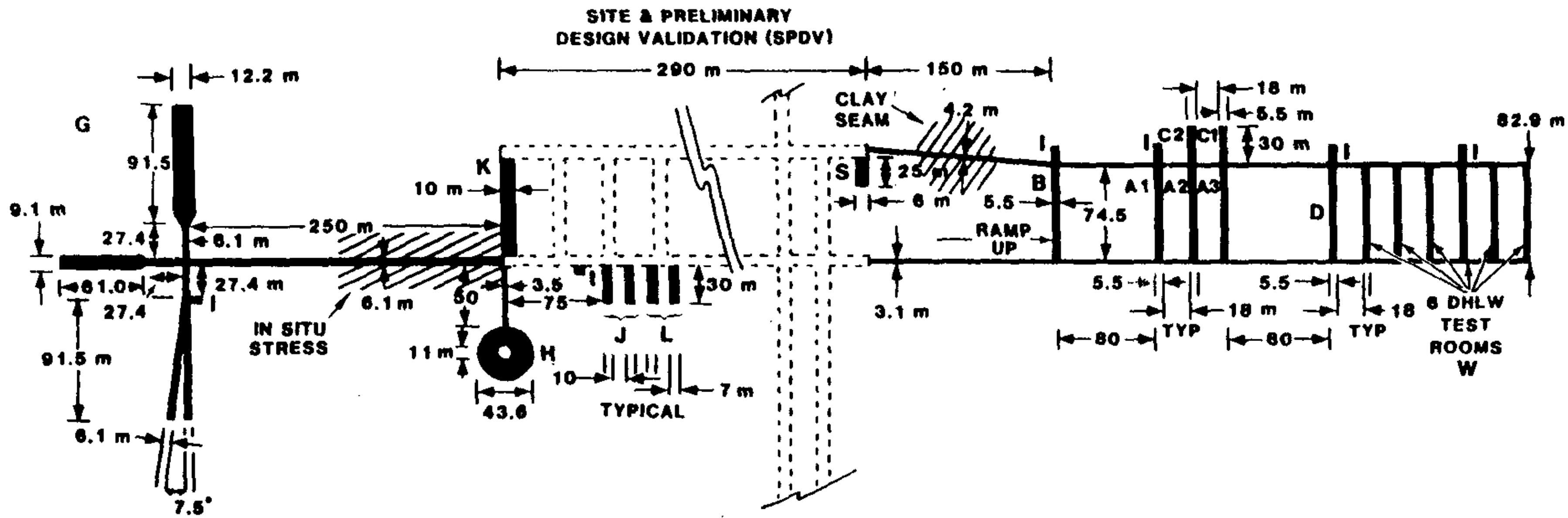


FIGURE 3-3 Schedule for WIPP in-situ tests. Source: Matalucci et al. (1982).



NOTES:

G. THE GEOMECHANICAL EVALUATION TESTS ARE ILLUSTRATED AS ONE TEST CONFIGURATION, BUT THEY CAN BE MODIFIED OR SEGREGATED INTO SEPARATE TESTS AT DIFFERENT LOCATIONS. FINAL CONFIGURATION WILL DEPEND ON FURTHER DESIGN CONSIDERATIONS.

I. INSTRUMENTATION ALCOVES (5 m WIDE, 10 m LONG, 3.1 m HIGH, TYPICAL)

S. WORKSHOP ALCOVE

(ALL DIMENSIONS IN METRES)

TESTS:

A. 12 W/m^2 MOCKUP
B. DHLW OVERTEST
C. MOCK DHLW EMPLACEMENT/RETRIEVAL DEMO
D. RADIATION-SOURCE EXPERIMENTS
G. GEOMECHANICAL EVALUATION
H. HEATED PILLAR
J. TRU DRUM DURABILITY (CH)
K. MOCK TRU DEMO (CH AND RH)
L. PLUGGING AND SEALING
W. DHLW TESTS

FIGURE 3-4 Layout of WIPP in-situ tests. Source: Matalucci et al. (1982).

diameter, about 700 m and 670 m deep, respectively, and extend more than 411 m into the 610-m-thick Salado Formation (Figure 1-2). The SPDV four-room test panel at the facility depth adjacent to the shafts has been completed.

Because the mechanical properties of the salt are considered by DOE to be important for facility design, geomechanical experiments were given the first priority for in-situ testing and were the only tests planned in the SPDV phase. These experiments consist of convergence and radial-motion measurements of the shafts, determinations of water pressure buildup behind the shaft liner, strain measurements in unlined sections of the shaft, monitoring of shaft-key loading and strain at the contact of the Salado with the overlying Rustler Formation, survey measurements at geometric grid points, and geologic mapping of lithology and structure. Matalucci et al. (1982) expected the SPDV tests to meet the following objectives:

o To validate the design for the WIPP access shafts and TRU waste disposal demonstration rooms.

o To evaluate the amount and rate of shaft convergence and room creep deformation and to correlate these data with model predictions.

o To perform a preliminary evaluation of creep in salt and of the steady-state creep model.

o To evaluate instrumentation systems for accuracy and the reliability of measurements made with them in rock salt and to document the suitability of the systems for future measurements.

o To evaluate the response of lithologic discontinuities such as clay seams and layers of other material in addition to the salt.

o To collect a large number of samples of rock salt and other materials and to conduct laboratory and bench-scale tests to determine the mechanical properties of these samples.

The WIPP design has to provide for long-term repository closure (which may extend beyond 200 years) by plastic flow, and also provide for short-term access (up to 25 years) for waste package emplacement and retrieval. A key problem of the SPDV was to test by very short-term measurement ($\sim$9 months) the validity of predictions from the (two-dimensional computer program) model of repository behavior over the long term. The SPDV report (U.S. Department of Energy 1983a, Table II, last row), implies that this is a routine check, with little expectation of surprises. Longer-term observations will be needed to confirm the degree to which the design requirements will be met.

The SPDV objectives that require extended observations have not as yet been fully achieved. Since the SPDV measurement phase will merge into the in-situ testing program, these objectives should be realized later in the program. For example, tests of interaction between waste and surrounding rock will follow the SPDV phase.

The panel regards the results of the SPDV and in-situ experiments as crucial in establishing the performance and safety of the WIPP repository. These results will provide a wealth of data concerning the behavior and properties of salt under repository conditions. The information could also be of great value in connection with other waste disposal activities.

It is important that effective and timely comparisons be made between theoretical predictions and actual measurements and observations made underground during these experiments, and during continued construction. Such comparisons provide an essential mechanism for developing and helping to validate the theories and understanding of behavior and properties upon which the design of the storage excavations is based. Theory and calculational methods used to predict the results of the experiments, and refined in the light of results from those experiments, provide an important basis for the qualitative and quantitative evaluation of the design of the storage area. It is important that the design of the storage area reflect the knowledge gained as a result of the experiments.

The principal purpose of the SPDV program was to verify whether or not the WIPP site is suitable for a waste repository. Geological and geophysical investigations from the surface, supplemented by drilling, had indicated that the Salado Formation and the adjacent strata would be a suitable host for a waste repository. However, surface exploration is necessarily limited in the extent to which it can resolve all factors of concern in the design and construction of a repository, especially where those factors involve details such as the stratigraphy within the Salado. It was, therefore, necessary to confirm the major characteristics of the site inferred from surface exploration by direct observation and measurement in underground excavations, as well as to resolve by underground experiments and observations many structural details and other factors affecting the design and ability to construct a repository.

IN-SITU TESTING PLAN

Bedded salt is a prime candidate to be the geologic medium for the emplacement of high-level radioactive waste, both civilian and military. The main information currently available on such emplacement comes from Project Salt Vault, a program conducted from 1965 to 1967 by the Oak Ridge National Laboratory using canister and instrumentation technology of the time in a salt mine. The WIPP facility offers an opportunity for professionally executed emplacement experiments, using present waste form concepts and equipment, in an actual repository operation. This will be possible years before any comparable repository is available. Results of experiments with high-level waste in WIPP can bring useful experience to the design of future repositories. Consequently, the opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the WIPP program.

Plans have been formulated and reported by Likar (1979) and Matalucci et al. (1982) for an R&D program that includes emplacement and retrieval of contact-handled TRU waste, remotely handled TRU waste, and defense high-level waste (DHLW); the investigation of interactive effects of heat- and radiation-generating waste packages with a salt repository; and the investigation of repository backfilling, plugging, and sealing. The program (see Figure 3-2 and Figure 3-3) began in 1983 and is scheduled to continue through the life of the facility. The test sequence begins with thermal-structural interactions to verify the ability of structural models to predict long-term repository response, and (assuming these results are positive) continues in stages to demonstration of DHLW retrieval from corroded and failed waste packages. Obviously, the earlier experiments are better defined than the later, which will allow for incorporation of the results from the early WIPP experiments and the ongoing parallel experimental programs into the plans for the later WIPP experiments. This is appropriate because, although the general philosophy appears to be that the experiments are "verifications" of present concepts and models, surprises almost certainly will be encountered, and new concepts and models relating to waste forms, waste package materials, design, dimensions, and heat outputs will evolve over the next decade.

The value of the experiments would be enhanced greatly by prompt publication of their results in scientific and technical journals in order to facilitate their consideration by the scientific and engineering community rather than only by those individuals involved directly with the WIPP project. To take maximum advantage of progress in waste disposal technology worldwide, the periodic revisions of the experimental program should be preceded by deliberate solicitation of ideas for experiments, instrumentation, and equipment from outside the DOE (cf. National Research Council 1979).

At present, WIPP is designed to accommodate a considerable variety of waste packages. While operational smoothness would benefit from fewer and better-characterized packages and waste forms, the small-scale mock contact-handled (CH) and remotely handled (RH) TRU waste-handling demonstrations in the experimental program (cf. Figures 3-2 and 3-3) should take advantage of the present lack of uniformity to make an operational input into the recommendations for size, shape, weight, and other criteria for the waste packages that will be used on a large scale.

Plans for the aboveground facilities and the number of shafts have recently been changed to reduce facility cost substantially, but at the expense of the rate of waste emplacement and of operational flexibility (see Chapter 5 for further discussion of these changes). The plant electrical system has lost some redundancy, which means that the electrical supply system for the experimental program cannot be relied on for those experiments and systems that demand an uninterrupted power supply (such as the brine migration experiments). The alternative facility orientation that has been chosen extends the storage area to the south of the present shafts instead of to the north, and would isolate the experimental area by 823 m from the storage area and from continuing construction and storage activities. This benefits both the experimental and the storage activities in a number of ways, including reduced chance of interference and continued availability. To complete the separation of experiments from construction and emplacement, it would be desirable to have separate radiation-monitoring facilities.

The WIPP FEIS and SAR (through Amendment 6) recognize that accidents associated with the experiments with DHLW constitute the largest risk of environmental contamination, of plant contamination, and of operator exposure. Complete procedures for carrying out these important experiments have not yet been written (nor is it reasonable to do so before more operational experience with less hazardous experiments has been gained). Previous hazard analyses contemplated no changes in the standard ventilation precautions, i.e., high-efficiency particulate air (HEPA) filters normally off-line, and cut in on detection of radioactivity in the vent stream. However, special precautions, such as putting the HEPA filters on line in advance of the experiment, might be considered as part of the operational procedures for experiments involving the handling of degraded DHLW canisters. The special ventilation requirements of the room experiments on brine corrosion, if a significant hydrogen sulfide content is introduced with the brine, also need to be developed.

The demonstration emplacement and retrieval activities will reveal any weaknesses (such as excessive time for operations) in the storage concepts (e.g., the sidewall emplacement of remotely handled TRU waste) or in the equipment procured to implement them, and deserve sufficient priority to allow alterations in advance of large-scale waste emplacement operations in the storage area. Remarkable progress is expected in the next half-dozen years in such areas as automated sensing devices, robotics, remote imaging, and instrumentation and control for hostile environments. These developments should be continually screened for application to waste isolation by testing in the WIPP R&D program.

Accelerated tests, such as room closure measurements with a heat source four times reference design conditions and experiments with higher-than-expected radiation levels, tackle the difficult problem of investigating long-term effects within the lifetime of one generation of experimenters. Overall, the approach is reasonable. Extrapolations from these experiments would be more convincing with practicable three-dimensional models and improved computer programs. One can reasonably expect to have these with the next generation or so of computers.

Since the number of experiments that can be undertaken in the WIPP project itself is finite, the number of variables that can be dealt with in the many combinations of waste package, canister overpack, backfill, or plugs and seals is limited. The usefulness of the WIPP tests could be improved by concentrating on the comparisons of in-situ tests with smaller-scale laboratory experiments. Laboratory tests paralleling the WIPP in-situ tests would reveal the differences, if any, between results of the two types of tests. This would serve to validate the cheaper and more convenient aboveground tests, thus improving the eventual rate of development of new materials. In general, inaugurating the WIPP in-situ testing program does not decrease the importance of the laboratory and field research programs that have contributed greatly to the choice of materials for the WIPP project.

CONCLUSIONS

o The in-situ test program is logically designed to explore the local waste package-repository interactions that would result from the emplacement, retrieval, and long-term isolation of TRU and high-level defense waste in salt beds (pp. 22-30).

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in an underground salt repository at depth, is an important aspect of the WIPP program (p. 29).

RECOMMENDATIONS

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU waste at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU waste (p. 20).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Outside developments in automated sensing, robotics, instrumentation in hostile environments, and so on, should be systematically screened for application or testing at the WIPP facility (pp. 29-30).

o Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation (p. 29).

o Separate radiation-monitoring equipment should be installed for the experimental rooms and the TRU waste emplacement areas (p. 29).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 30).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate that form of testing so that the matrix of tests can be expanded by the less expensive laboratory experiments rather than by further in-situ testing (p. 30).

CHAPTER FOUR

WASTE ACCEPTANCE CRITERIA

The definitive statement of the TRU waste acceptance criteria for the WIPP project is contained in WIPP-DOE-069 (U.S. Department of Energy 1981). A summary of these criteria appears in Table 4-1.

The waste acceptance criteria are for the most part quite straightforward. They are concerned with establishing standards on dimensions, weight, radiation levels, and the like, such that operational difficulties and health hazards at the WIPP site will be minimized when waste emplacement actually begins. The criteria permit a surprisingly wide variety of containers and waste forms, but this reflects the practical consideration that existing stored waste is heterogeneous in terms of composition, physical state, and package configuration.

Evidently, the philosophy has been adopted that minor inconveniences at the WIPP site are less consequential than the major ones that would occur at the various storage sites if highly restrictive criteria were adopted. These inconveniences are acceptable on an interim basis, but it should be a stated objective of the lead management organization of the defense TRU waste program to work as rapidly as possible toward standardized packaging of fully characterized and thoroughly stabilized waste.

The most debatable of the criteria are those related to the inclusion of organic materials in the waste. The presence of substantial amounts of such materials raises questions about combustibility in the short term and about gas generation, complexation, and possibly accelerated radionuclide transport in the long term.

FIRE

Underground fires, as is well known from coal mining experience, are particularly difficult to control. In practice, it has proved to be very difficult to extinguish such fires because underground combustion sites are so well insulated thermally.

Fire prevention and control will, of course, be easier in a salt repository than in a coal mine. For fire safety, however, the waste disposal configuration should be such that a fire would self-extinguish without any control measures whatever.

TABLE 4-1 Waste Acceptance Criteria for Contact-Handled and Remotely Handled TRU Waste

Criterion	Contact-Handled TRU Waste	Remotely Handled TRU Waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpacked in steel. Packages containing over 25 volume percent combustibles shall be color coded.	Noncombustible containers
Gas generation	Gas generation by all mechanisms must not exceed 10 moles/m^3 of disposal-room volume per year under repository conditions. In terms of waste composition, this criterion may be interpreted to mean that the average organic content of contact-handled TRU waste may not exceed 14 lb/ft^3 for waste in 55-gallon drums and 6 lb/ft^3 for waste in other containers.	No criterion; quantities are insignificant
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix if over 1 percent by weight of fines less than 10μ, or 15 percent less than 200μ.	Same as for contact-handled TRU waste
Explosives and compressed gases	None, as defined by 49 CFR 173, Subparts C and G.	Same as for contact-handled TRU waste
Pyrophorics	Small quantities (up to 1 percent of the waste by weight) of radionuclide-metal pyrophorics may be accepted with other waste forms if they are dispersed throughout the waste. Larger quantities must be processed to remove their hazardous properties.	Same as for contact-handled TRU waste
Toxic and corrosive materials	Toxic materials allowed only with special authorization and precautions; corrosive materials must be neutralized or otherwise rendered noncorrosive.	Same as for contact-handled TRU waste
Sludges and free liquids	Sludges shall be packaged in such a way that internal corrosion protection is provided for the waste container.	Same as for contact-handled TRU waste
	CONTAINER	
Structure	Type A requirements, noncombustible, with 15-year design life after emplacement, to allow retrievability. If visibly bulged or damaged, must be overpacked.	Same as for contact-handled TRU waste
Handling	Devices to allow handling by a forklift, etc.; no interference with stackability.	Axial lifting pintle only
Weight	No more than 25,000 lb.	No more than 7,000 lb.
Dimensions	Not larger than 8 by 12 by 8.5 ft.	24-in diameter, 10-ft length
Surface-dose rate	Not exceeding 200 mrem/h at any point. Containers with a surface-dose rate in excess of 10 mrem/h must be color coded.	Less than 100 rem/h
Surface contamination	Not more than 50 pCi/100 cm^2 for alpha, and 450 pCi/100 cm^2 for beta-gamma emitters.	Same as for contact-handled TRU waste
Criticality	30-gal drum, 100 g fissile; 55-gal drum, 200 g fissile; DOT 7 a package, 350 g fissile; other boxes less than 5 g in any cubic foot.	No more than 5 g/ft^3, unless specifically authorized by WIPP
Thermal power	Container must be color coded if the thermal power exceeds 0.1 W/ft^3.	No more than 300 watts per package.
Labeling	In addition to other requirements: a package identification number, and weight in kilograms.	Identification number only

SOURCE: After U.S. Department of Energy (1981).

A self-extinguishing configuration can be provided by stacking of the waste packages in such a way that combustible and noncombustible materials are intermixed as intimately as package configurations permit, in a proportion such that the heat liberated by oxidation of the combustible component is sufficiently dissipated to prevent the temperature of the mixture from reaching the ignition point of the organic materials. A conservative a priori calculation of sufficient accuracy should be quite simple, given the data on maximum organic content of each package that is part of the waste certification documentation. Naturally, the backfill salt is important as a noncombustible component in this calculation.

A self-extinguishing configuration does not, of course, eliminate the possibility of transient underground fires arising from transporter accidents, electrical faults, or welding that may involve one or more waste packages. The provision for handling such situations has not yet been specified (U.S. Department of Energy 1980-1983). This must not be overlooked as the operational period approaches. In particular, in the case of fire it is recommended that the flow of ventilation air not be interrupted, so that the flow of heat and fumes will be away from personnel and into the waste stack, where combustion will soon self-extinguish. It is also recommended that major reliance be placed on small, portable, fire extinguishers kept in the operational areas, rather than on large, centralized fire equipment.

GAS GENERATION

Pure polycrystalline halite, well consolidated, is nearly impermeable to fluids. This is one of the properties that first drew attention to bedded salt as a desirable medium for the storage of nuclear waste. However, given the fact that organic waste will almost certainly generate a certain amount of gas, it becomes necessary to examine the possibility that a sealed repository might self-pressurize to a degree that would be dangerous. A reasonable choice for the danger point is a gas pressure equal to the lithostatic pressure at the repository depth. For WIPP, this is approximately 150 atmospheres (15 MPa).

Machine computations have been made of predicted gas pressure, with time and permeability as parameters. The added effect of salt flow was considered in some cases, but the model on which specifications were based was a rigid void of the intended drift dimensions, filled to 75 percent with incompressible material. Gas was dissipated by porous-medium flow in two dimensions (U.S. Department of Energy 1981, Sandia National Laboratories 1979).

A crude estimate of the anticipated gas generation rate was made in the same documents, as follows: A reference 210-liter waste drum was defined to contain 60 kg of organic waste, of which 20.5 kg was polyethylene and the remainder other plastics and cellulose. A total gas generation potential of 5,600 mol per drum was projected by assuming that through some combination of processes, all the organic material could be converted to gas. For example, it was assumed that each methane subunit of polyethylene could be converted to 1 mole of hydrogen and 1 mole of carbon oxides. In recognition of the certainty that conversion would not be complete, the practical gas production potential was arbitrarily scaled down to 2,000 mol per standard drum. Using the assumption that the gas generation period is 400 years, a mean gas generation rate of 5 mol per drum per year was indicated.

This gas generation rate, combined with a permeability of 0.1 microdarcy, was computed to give a peak (not steady-state) pressure somewhat less than that of the overburden in 400 years. Gas permeabilities measured in Salado boreholes gave somewhat variable results of the order of 10 microdarcies. It was concluded that a gas generation rate of 5 mol/yr per drum is acceptable. In the panel's opinion, the safety factor of 100 is adequate to allow for the evident uncertainty in the actual effective value of the permeability. The higher permeability figures from the field are in fact likely to be more realistic, because the bedding-plane seams of clay and anhydrite are likely to be major contributors to in-situ permeability.

The gas generation limit in terms of disposal-room volume (10 mol/m^3) was derived from consideration of the repository space allotted to each drum. This same limit, restated in terms of organic waste per unit of package volume, is lower for boxes because they pack more densely than do drums.

Another estimate of the probable gas generation rate was made by totaling the contributions of four processes: radiolysis, thermal degradation, bacterial degradation, and chemical corrosion. Production of helium by alpha decay was found to be negligible. After an extensive program of literature study and experimental work, a "most probable overall average" gas generation rate for existing Idaho National Engineering Laboratory (INEL) TRU waste was estimated to be 0.3 to 1.4 mol/yr per drum, with 0.0005 mol/yr as the lower limit, and 2.8 as the upper limit (Molecke 1979).

Thus, the crude a priori estimate and the experimentally grounded estimate give comparable results, and the gas generation rate in both cases is comfortably within the limit determined by the pressurization criterion.

The panel thinks that the "most probable" gas generation estimate is probably too high. It has been reported (Sandia National Laboratories 1979) that the process making the major contribution to gas generation is bacterial attack on organic materials contained in the waste. However, the experiments upon which this conclusion was based did not address adequately a basic question: Is the repository humidity* high enough to support active microbial metabolism after exhaustion of the moisture in the drums? Microorganisms are critically sensitive to ambient humidity because of their high surface-to-volume ratio. Most species require a humidity of 90 percent or higher for growth (inactive spores may of course survive at low humidity for long periods). A

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*Relative humidity of the repository atmosphere at equilibrium with the host rock. This is a measure of the thermodynamic activity of water in the microbial environment.

literature survey (Horowitz 1979) found no confirmed reports of growth at humidity below 60 percent.

Air in contact with saturated sodium chloride brine has a humidity of 70 to 75 percent. If calcium and magnesium chlorides are present as grain-boundary phases in Salado salt, their saturated aqueous phases could maintain the humidity of a sealed repository as low as 20 percent. Now that the SPDV program has made the Salado directly accessible, measurements of humidity should be made in a freshly excavated still-air cavity.

Even without measurements, the existence of low humidity, coupled with a large water-absorption capacity at the storage horizon, may be inferred on thermodynamic grounds. The anhydrous calcium sulfate (anhydrite) that occurs plentifully in seams throughout the Salado would have become hemihydrite or gypsum had the thermodynamic activity of water been high enough. Dissociation pressures of calcium sulfate hydrates and other salt phases taken from the chemical literature should set an upper limit for the humidity of the repository after sealing.

The desiccating effect of the salt will not, of course, immediately penetrate to the interior of sealed drums, but the appropriate time scale on which to evaluate the "breathing" of drums may be centuries. During such a lengthy time period, a drum sealed in the conventional manner with an elastomeric gasket can be expected to lose most of its initial water content. Internal corrosion and eventual crushing by drift closure will tend to hasten the release of water.

The experimental work reported by Sandia National Laboratories (1979) may not have considered the general principle that metabolic activity is poisoned by the accumulation of metabolic products. This will tend to limit the pressure generated by any gaseous metabolic product. The study failed to observe methanogenesis, which indicates that anaerobic conditions were not fully achieved in the experiments.

Questions about the availability of adequate supplies of phosphorus and fixed nitrogen were handled by making the conservative arbitrary assumption that these are not limiting factors.

The discussion of microbial gas generation in DOE's TRU waste acceptance criteria (U.S. Department of Energy 1981) makes no mention of the possible role of the sulfates that are present in the Salado salt. It is known that methanogenesis does not normally occur in the presence of sulfates (Weiss et al. 1982). Hydrogen sulfide, carbon dioxide, and hydrogen are produced instead. The role of sulfates will not be significant unless the repository becomes flooded; otherwise there is no mechanism for bringing sulfates into intimate contact with the organic substrates. However, should flooding occur, a worst-case scenario is conceivable in which the gases generated by ordinary microbial action are augmented by hydrogen sulfide, and the pressure of the acidic gases, carbon dioxide and hydrogen sulfide, builds to the point that the brine dissolves the steel of the drums and of the box overpacks. This will generate up to 430 mol of additional hydrogen per drum. The corrosion of steel by pressurized brines containing acidic-gas solutes is well known from oil field experience (Shock 1953).

The biochemical situation is obviously very complex, but our knowledge of life in extreme environments can probably serve as a basis for reliable predictions. The probability of flooding of the repository following decommissioning is likely to be quite small for a long but undefined period because salt has such low permeability. However, it is the opinion of the panel that the potential for flooding merits further study, because some geologists believe that void spaces in salt repositories will eventually fill with brine. Water may flow along shaft backfills, along sheaths of damaged rock located immediately adjacent to shafts and drill holes, above rooms and tunnels, and through clay and anhydrite interbeds and salt. Salt may be capable of transporting brine from adjacent sources, especially if confining beds are adversely disturbed by repository development.

RADIOLYSIS

Radiolysis is also discussed in the references already cited. Because of the low level of radioactivity in typical TRU waste, even the remotely handled TRU waste, the rate of radiolytic gas generation is considered to be a small fraction of that assumed for microbial action. The panel accepts the position that radiolytic gas generation can be neglected from the standpoint of repository pressurization.

There is, however, an interesting special case of radiolytic gas generation. New Mexico's Environmental Evaluation Group (EEG) called attention to this in EEG-24 (Neill and Channell 1983). The Savannah River Plant and Los Alamos National Laboratory produce substantial amounts of waste contaminated with plutonium-238 as a by-product of the fabrication of nuclear heat sources. Because of the relatively short half-life of this isotope, a drum of such waste may be quite high in alpha activity. It has been estimated that 700 to 1,000 drums of currently stored waste contain more than 100 Ci per drum. Many (perhaps most) of these drums contain cellulosics and polyethylene. It is known from laboratory studies (Bibler 1976) that hydrogen and carbon dioxide, with traces of carbon monoxide and methane, are produced by alpha radiolysis of these materials. The G value (molecules of gas produced by absorption of 100 eV of radiant energy) is dependent on both dose and dose rate, but an appropriate figure is 1.9. Thus, a drum containing 100 Ci of plutonium-238 would be expected to produce 0.055 mol/d of a mixture of hydrogen and carbon dioxide. The proportion of the two gases depends on the substrate. Polyethylene yields nearly pure hydrogen, but cellulosics yield about 0.7 mol of carbon dioxide per mole of hydrogen.

Pressurization of drums from radiolysis has been found not to be a problem because the standard elastomeric seal ring is not entirely leak-tight. Furthermore, hydrogen diffuses especially rapidly through elastomers.

Bibler (1976) has observed that the oxygen initially present in the container is essentially all consumed by reaction with carbonaceous material before significant accumulation of hydrogen occurs, regardless of the nature of the organic substrate. This means that the generation of an explosive mixture within a waste drum is unlikely except for special circumstances such as the "breathing" of a drum during temperature or altitude changes. Field reports of the occurrence of explosive mixtures (Ryan 1982) are to be ascribed to this, and to contamination of samples by air.

The term "explosive mixture" gives an erroneous impression of the hazard associated with mixtures of hydrogen and oxygen that are extensively diluted with nitrogen and carbon dioxide and that occupy the interstices of a container filled with solid waste. Even if a source of ignition is present, the inert gases and solid waste cool and slow the flame front so that the resulting pressure transient is very gentle. After the reaction, the pressure in the drum will fall below ambient because a small volume of liquid water replaces a larger volume of hydrogen and oxygen.

A potentially serious situation might develop if a transport container (TRUPACT) were entirely filled with high-curie waste drums, each drum exhaling a gas mixture rich in hydrogen. The TRUPACT is vented, but not ventilated; so given time, an explosive mixture might develop (NRC regulations do not permit such venting). Obviously, it will be prudent to set a reasonable limit on the number of high-curie packages that may be shipped in a single TRUPACT when and if it is decided that high-curie drums will be sent to WIPP.

In view of the minor importance of gas generation for projected TRU waste, consideration should be given to relaxing the waste acceptance criterion relating to gas generation, particularly if the humidity in the repository proves to be less than 60 percent. Nevertheless, the emplacement density of organic materials should be limited to conform with the criterion of self-extinguishment stated above. Rough calculations indicate that the restriction on organic material imposed by this requirement is easily met.

COMPLEXATION

Many documents, including the SAR (U.S. Department of Energy 1980-1983), examine the consequences of scenarios in which the Salado salt containment is breached. Radionuclides then move upward into the aquifers of the Rustler Formation and thence by hydrologic flow to the surface at Malaga Bend or elsewhere. Sorption by the clays and dolomites of the aquifers has been experimentally shown to be very strong for plutonium and its daughters, which leads to a significant retardation of the transport of those species with respect to the groundwater flow. Complexation of the actinides by organic materials included with or derived from the organic component of the waste will interfere with the sorption process and shorten transport time accordingly.

A sensitivity analysis of the consequences of the reduction of K_d, the distribution coefficient, by complexation is reported in SAND 79-1305 (Sandia National Laboratories 1979), and a similar analysis appears in EEG-8 (Wofsy 1980). Both analyses conclude that even complete elimination of the sorption effect would not increase the dose commitment to the maximally exposed individual to parity with the dose received from natural sources, owing to the long travel time for the water.

The FEIS does not mention complexation as a factor in the establishment of waste acceptance criteria. Within the limits of the particular scenarios considered in the FEIS, the omission probably is justifiable. In other possible scenarios, where flow occurs through fracture systems, or in the extreme case through karst, both travel time and solution-soil contact would be drastically reduced. Sorption would then become a matter for more careful evaluation. The possibility of fracture flow is discussed briefly at the close of Chapter 6.

CERTIFICATION

The best possible set of waste acceptance criteria is of doubtful effect unless compliance is continually and systematically verified. Misgivings on this point have been expressed by the New Mexico EEG and by this panel. Recent briefings and recently released documents (U.S. Department of Energy 1982; Whitty et al. 1982) are making it clearer how compliance can be assured.

A particularly important part of the certification strategy, and one that this panel supports, is the policy of beginning certification with newly generated waste. This postpones the serious problem of determining exactly what is contained within old packages that have inadequate documentation. Certification will not begin at any waste-generating site until appropriate procedures have been developed, facilities built, and personnel trained, all of which are easier with newly generated waste.

At an October 1983 briefing, the panel was given an outline of the review process that is to occur before certification begins at any waste shipment site. Each of the 10 sites is to design a Certification Plan and submit it to the five-member Waste Acceptance Criteria Certification Committee. This committee has authority to require an iterative reworking of each plan.

Next, the New Mexico EEG is given an opportunity to comment, which may lead to further iterations. Finally, if the WIPP Project Office finds the plan acceptable, the shipper is notified and waste certification may begin at that site, subject to periodic quality assurance audits.

This procedure is obviously quite cumbersome. Rocky Flats, the first site to submit a plan in December 1981, was in its sixth iteration in October 1983. Final approval is projected for 1984.

The panel believes that much of this red tape and delay could be eliminated by following the procedures universally and successfully used by major purchasers of commodity items in the world of commerce. A specification is published and suppliers ship only goods that they believe will meet the specification. Compliance with the specification is verified by the purchaser at the location where the goods are delivered. Off-specification goods are returned or accepted with an appropriate penalty to the supplier.

The elaborate Certification Committee procedure was apparently conceived in an effort to forestall any possibility of the arrival at

WIPP of goods (waste packages) that do not meet the specifications (the waste acceptance criteria). Yet, WIPP does not (and cannot) rely entirely on prior certification. The WIPP Project Office, in fact, plans to have at the receiving building the equipment necessary for making a thorough final inspection of at least a sample of the waste packages as they are delivered. It is, therefore, not clear what is accomplished by the lengthy iterative procedure. The procedure will, in fact, be counterproductive if it tempts WIPP to place complete reliance on inspections carried out before shipment at a remote site. Centuries of commercial experience have taught that inspection of goods on delivery is the only reliable way to ensure quality.

After all newly generated waste has been certified, it will be necessary to deal with stored waste. That of recent origin--since 1970, approximately--is stored retrievably and is comparatively well documented. Waste in this category that is stored at Idaho National Engineering Laboratory (INEL) will be processed along with newly generated waste. Stored waste from other sites will be processed later, with technology developed at INEL in the Stored Waste Examination Pilot Plant (SWEPP) and Process Experimental Pilot Plant (PREPP) programs. Technology for preparation and transportation of remotely handled TRU waste is also to be developed in this second phase.

The purpose of SWEPP is to effect a separation of the stored waste packages into two groups: (1) those that can be immediately certified and (2) those that cannot. For certification purposes, the waste acceptance criteria have been elaborated as "Compliance Requirements" in the WIPP/DOE-137 report (Rockwell International 1982). This document addresses the rather troublesome question of how to treat those packages that may be certifiable, but are not adequately documented as to contents.

Apparently it is intended that undocumented packages not be opened: "nondestructive examination" will be undertaken. The techniques to be used are not adequately described, and indeed are evidently still under development. Briefing has revealed that visual inspection will be supplemented by ultrasonic determination of metal thickness where corrosion is suspected, neutron assay for fissionable-isotope content, and "real-time radiography" for internal examination.

It is anticipated that as much as 30 percent of the waste will have to be classified as uncertifiable for one reason or another. Such packages will be transferred to the PREPP. A test unit was constructed in 1982, and the operating principles were adequately demonstrated in tests on simulated waste in September of that year. The plant includes an impact mill that is capable of coarsely shredding both metal drums and wooden boxes. The product is fed to a gas-fired incinerator. The resulting ash is screened. The coarse residues are loaded into steel drums and "potted" in a hydraulic cement that includes the fine fraction as part of the aggregate.

The panel has not had an opportunity to inspect the PREPP, but it is reassuring to learn that the incineration process is much like that which is used routinely in the disposal of municipal waste. The more elegant but less familiar concept of fusing the ash into a slag has been abandoned as impractical.

The panel has not received any safety analysis of the PREPP operation, but standard techniques should be sufficient for protection of operators and the environment, particularly if only contact-handled waste is to be processed. There is apparently no intention to use the PREPP technique with remotely handled waste.

A certification procedure cannot be truly meaningful unless a practical alternative exists for handling waste that fails to meet the criteria. The pyrolysis option, or possibly others, should be pursued vigorously for this purpose.

DEFENSE HIGH-LEVEL WASTE

The WIPP mission includes a program of experiments with retrievably emplaced, high-level waste, presumably solidified in glass and contained in metal canisters. No criteria have been written for this class of waste, even though the experimental area has been laid out and tentative plans for experiments have been formulated. These criteria should be prepared well in advance of need.

CONCLUSIONS

- The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (p. 34).
- Criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity (p. 36).
- If the repository should become flooded with brine, the presence of sulfates might entail a new scenario: the biological generation of hydrogen sulfide and chemical dissolution of the steel drums, with generation of hydrogen (p. 37).
- From the viewpoint of the WIPP facility, the quality assurance system is inadequate in that it requires no on-site verification of conformance of package contents to the certification (p. 40).
- The Certification Committee procedure is cumbersome and may even be counterproductive (pp. 39-40).
- The PREPP incineration process appears to be an appropriate and practical technology for processing contact-handled waste that cannot be certified in the original packages (pp. 40-41).
- No procedure has been established for dealing with uncertifiable remotely handled waste (p. 41).

RECOMMENDATIONS

- As soon as is feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 32).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (p. 34).

o The existing deficiency in the Safety Analysis Report (U.S. Department of Energy 1980-1983) on procedures for fighting transient underground fires should be remedied (p. 34).

o The humidity of still air in equilibrium with the salt and the pH of moisture in contact with the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 36).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (pp. 35-36, 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (pp. 35-36).

o The certification procedures, especially those for inspection of waste packages upon delivery to WIPP, should be redesigned to simulate those used commercially in the purchasing of commodities (p. 39).

o Procedures should be established for dealing with (1) uncertifiable remotely handled waste, and (2) high-curie contact-handled waste (pp. 37-38).

o Waste acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The criteria should be written early enough to allow time for review before experimental operations begin (p. 41).

o Consideration should be given to relaxing the waste acceptance criterion relating to gas generation due to bacterial action (p. 38).

CHAPTER FIVE

DESIGN AND CONSTRUCTION OF UNDERGROUND FACILITIES

Plans for the WIPP design, construction, and operation have changed continuously, and further changes can and should be expected. Flexible planning enables changes to be made to the design, construction, and operation of the proposed facility in the light of new information that emerges from the WIPP program and from other relevant programs. One important result of such changes has been to improve confidence in the predicted performance and safety of the facility. In this respect, explicit arrangements should be made to utilize the results from the in-situ tests in the final design and performance assessment of the repository. Another important result has been to effect economies in the design of the proposed facility. However, great care must be taken to ensure that such economies do not impair the performance and safety of the facility.

Although collection and analysis of data from the Site and Preliminary Design Validation (SPDV) program are not yet complete, the data that have become available as a result of sinking two shafts, driving drifts to the north and south edges of the repository, and excavating of the four test rooms, have provided important and necessary verification of the suitability of the WIPP site as a host for a repository and of the constructability of a repository at this site.

Both the exploratory and the ventilation shafts were sunk by large-diameter drilling. This has not only proved the practicability of construction, but has also provided essential verification and further detail of the lithologic and petrologic succession. The exploratory shaft has a steel lining that terminates in a concrete key at a depth of 268 m below surface, that is, at the contact between the Rustler and Salado formations. Accordingly, detailed inspection of the strata penetrated by this shaft could be made only below this depth. However, the ventilation shaft is lined to a much shallower depth, and this has permitted direct evaluation and logging of the beds from a depth of 30 m to about 660 m below surface. The horizontal persistence of the strata and lithology to the north and south edges of the repository area has been checked by logging at elevations from about 15 m above the repository horizon to about 15 m below it and by correlations established in the horizontal drifts and core holes drilled from them. This information has allowed a selection to be made of the best depth below surface for the proposed repository excavations.

Observations in the shafts and in the horizontal drifts have confirmed that the geology at the WIPP site very closely resembles that inferred from the surface exploration, and sinking of the shafts and excavation of the drifts have shown that there are no major practical impediments to the construction of a repository at this site. Nevertheless, many important factors that may still affect the design and construction and final performance of the proposed repository remain to be evaluated. These factors include the important effects of stratigraphic discontinuities in the Salado on the mechanical and hydrological integrity of the repository, the effects of creep closure of the excavations on retrievability, on the ultimate encapsulation of the waste by the salt, and on the reconsolidation of the backfill. Extensometer measurements in the shafts, horizontal drifts, and test rooms of the SPDV already provide important data concerning these factors, and the planned in-situ tests will provide more such data. Analysis of these data is essential to ensure that the mechanical properties of the salt and the effects of the stratigraphic discontinuities that these data reflect are taken into account properly in the final design of the repository and in the assessment of its performance and safety. Where measurements and observations produce unexpected results, it is necessary to incorporate the findings of these results into the final design of the repository or, at a minimum, to show that they are not indicative of behavior and conditions that would affect the performance and safety of the repository adversely.

UNDERGROUND EXCAVATIONS

Once a suitable site for an underground nuclear waste repository has been selected, one of the most important factors--if not the most important one--contributing to the successful disposal of radioactive waste is the design of the excavations and associated facilities that constitute the repository. Mining engineering provides a wealth of experience related to the design and construction of a repository, but the function of a repository is very different from that of a mine. The principal objective in mining is to remove as much of the ore as is practicable, consistent with short-term safety. The principal objective in making repository excavations is to remove only limited amounts of rock and thereby disturb the geologic media as little as is practicable, so as to ensure long-term safety and effective isolation of the waste.

Adequate conceptual design of an underground repository requires recognition that the properties of a geologic medium, even salt, may not be uniformly satisfactory over the dimensions of the proposed repository site, and that many variations in the properties and structure of the salt at the depth of the repository will be revealed only as the excavations are made and related experiments are carried out. Some of these variations may lead to unexpected difficulties in excavation or they may adversely affect the ability of the salt or the overlying strata to isolate the waste from the biosphere. Accordingly, it may be desirable to treat some portions of the repository differently from others and perhaps even to exclude some portions of the site from use for the waste disposal.

For these reasons, and to limit the extent of any accidents that may occur prior to final sealing of the repository, such as the intersection of a brine-filled void or the outbreak of a fire, the repository has been laid out as a number of independent modules. Substantial barriers of undisturbed salt will be left between modules to ensure that each module can be isolated effectively from every other module. No more accessways than are necessary for safe development of a module should penetrate these barriers, and each accessway should be provided at either end with a bulkhead that can be closed quickly if necessary. Ultimately, these accessways should be sealed permanently with a fill having low porosity and permeability. Devices for temporary closure of accessways, in the form of ventilation doors and other fabricated bulkheads, have been developed and are used extensively in the mining industry. In mining, permanent closure of accessways is usually effected by the construction of concrete plugs. For the WIPP site, a salt aggregate could be used so as to give the plugs properties compatible with those of the surrounding salt. No details are given in the program documents available to the study panel of devices for either temporary or permanent closure of accessways.

The current design (Figures 5-1 and 5-2) comprises three shafts: (1) a construction and salt-handling shaft, (2) a waste shaft, and (3) an exhaust shaft. An experimental area is laid out to the north of these shafts, and the storage area is laid out to the south of them. Access from the shafts to the experimental and storage areas is by parallel entries, two to the experiments and four to the storage area. The entries to the storage area (Figure 5-2) are separated from one another by wide pillars penetrated at intervals by crosscuts.

The storage area, measuring 629 m by 778 m, comprises four panels on each side of the main entries. Within each panel are seven storage rooms, measuring about 10 m wide by 4 m high by 91 m long, with their long axes parallel to the main entries, and separated by salt pillars 30 m thick. The panels are separated from one another by wide barrier pillars. Access from the main entries to the panels is by crosscuts at intervals corresponding to the length of the rooms and the thickness of the intervening barrier pillars, respectively. The overall extraction ratio is less than 25 percent, and the layout of the panels constitutes effective modularization, provided that the penetrations of the pillars can be closed effectively, both temporarily in an emergency and permanently after storage has been completed.

A fundamental advantage of salt as a medium for a waste repository is the prospect it offers for the ultimate encapsulation of the waste and sealing of the excavations by creep deformation of the salt. Every effort should be made to determine whether or not sealing and encapsulation will in fact occur and, if it does occur, when it will become effective as a means for isolating the waste. The extensometer measurements reflect the influence of many different factors on the response of the salt to the repository excavations. These factors include the mechanical properties of the salt and some of the effects of discontinuities, such as layers of clay or anhydrite within the salt, as

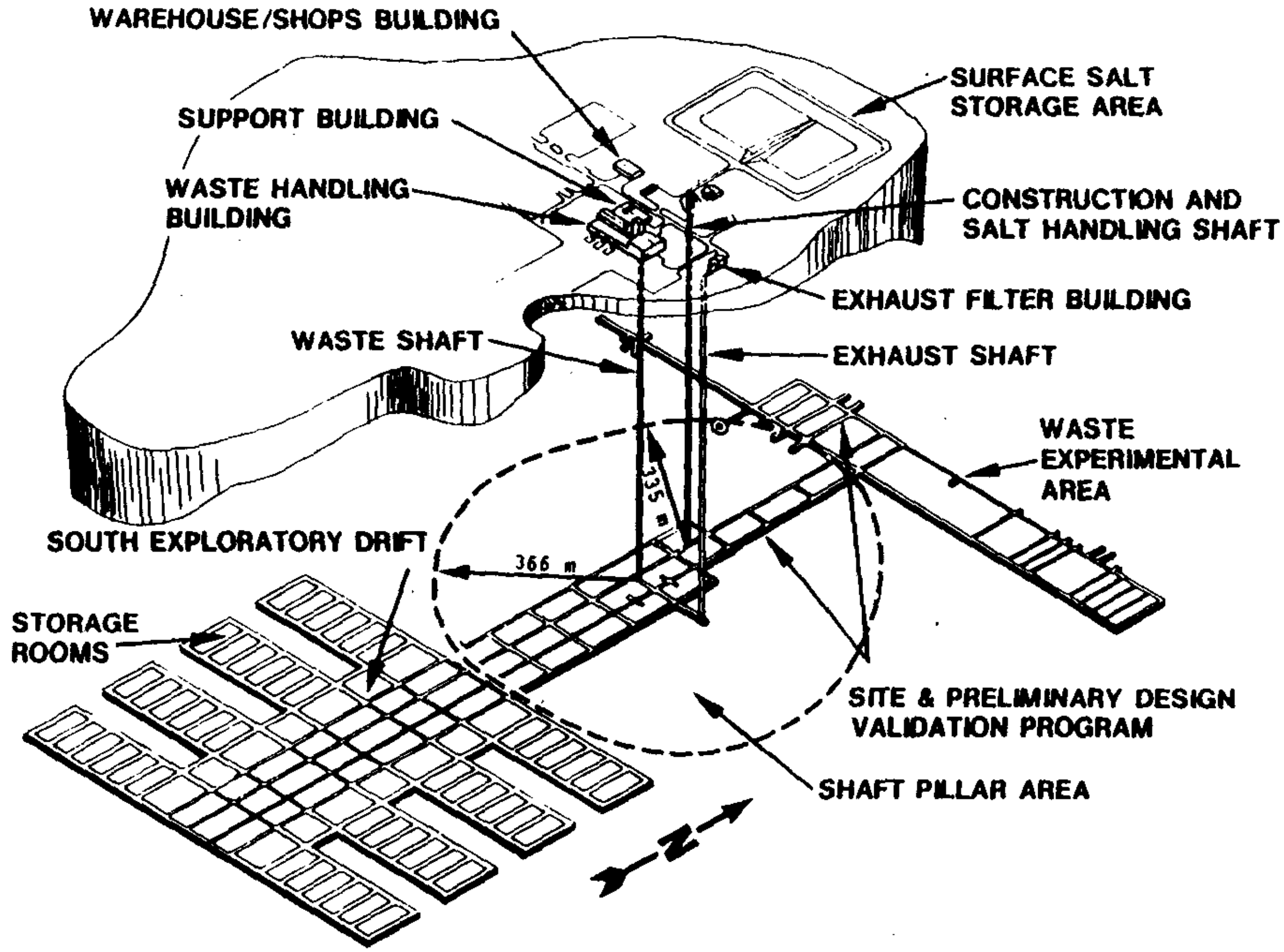

FIGURE 5-1 Cutaway diagram of the WIPP underground design. Source: After Bechtel National, Inc. (1983).

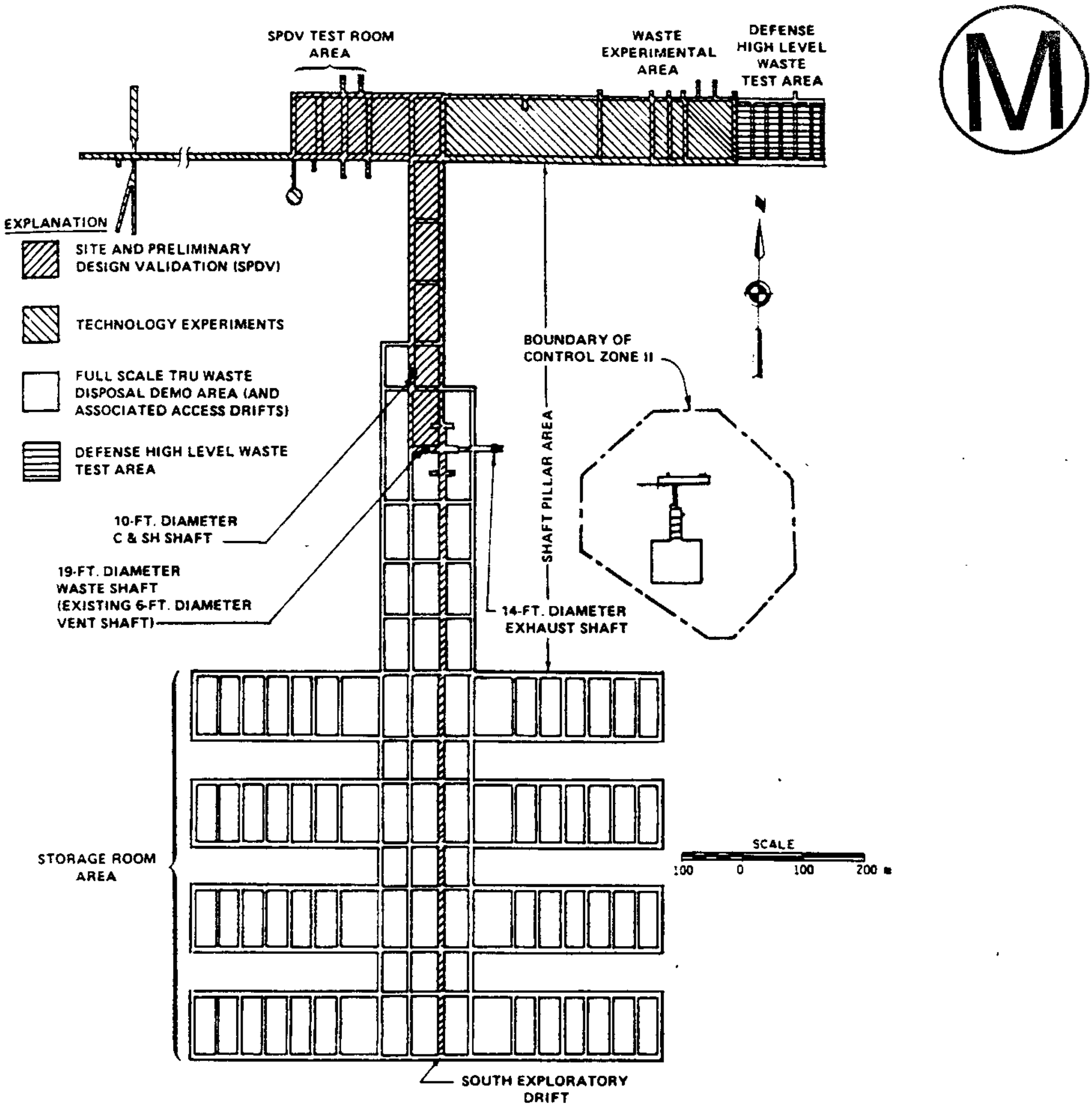

FIGURE 5-2 Plan view of WIPP excavations. Source: After Bechtel National, Inc. (1983).

well as the effects of the geometry of the excavations. Numerical models that have been used and will be used to evaluate the design and performance of the repository must include all these factors. It is unlikely that the properties of the salt over all times, from several seconds to thousands of years, can be represented by a single constitutive law. However, it may prove practicable to place bounds on maximum creep rates and hence on the minimum period of time before closure and encapsulation are effective. Many other factors such as the geometry of the excavations and stratigraphic discontinuities in the salt will be important in the evaluation of the behavior and response of the salt around the excavation at different times.

Measurements of deformation and closure from the SPDV and in-situ tests should be examined using numerical and theoretical models, both in the short term, when they can be compared with actual measurements, and in the long term, to assess what constraints the logic of the models and assumptions about the constitutive laws for salt impose on the closure of the repository excavations. Specifically, models should be used to explore closure of the excavations in the long term, say 100 years, 1,000 years, and more. Although validation of the models for such long periods may be impractical, it is important to assess qualitatively and quantitatively the rates of long-term closure and to determine how these rates are affected by the properties of the salt and the geometry of the excavation.

A proper analysis of long-term closure is necessary to arrive at a decision concerning the function of backfilling. If closure and encapsulation of the waste will occur within a usefully short period of time, say, 1,000 years, the backfill will be needed only for a period of time shorter than this. On the other hand, if closure cannot be relied upon to seal the waste in an impermeable surround of salt, the backfill probably will have to be designed to fulfill a long-time performance role. Finally, the nature of the backfill itself may affect the time to closure; low-porosity backfill may be used to shorten the time taken to achieve closure of the excavation. Salt removed during repository excavation is to be stored on the surface and eventually used as backfill material. Excessive moisture in the backfill salt is not expected to be a problem, in view of the generally arid climate and the protective crust that forms on the piles during surface storage. However, prior to actual backfilling, the matter of moisture content of the material should be reexamined.

In the near field, the excavations of a repository make up a network of interconnected hydraulic conduits in the salt mass at the repository horizon. Closure of the excavations, even in the long term, say beyond 1,000 years, may not reduce the void space in the waste and backfill to a negligible value, so that the backfill may have a porosity much greater than that of the intact salt. Unless it can be shown that this residual void space does not result in a hydraulic conductivity through the repository excavations that is significantly greater than that of the pristine salt, a careful analysis of the effects of void space on the hydraulic conductivity should be made. Alternatively, it may be shown that the consequences of such conductivity would not be expected to be greater than those resulting from scenarios of water flow between two aquifers (Bingham and Barr 1979).

CHANGE FROM FOUR SHAFTS TO THREE SHAFTS

The original designs for a repository at WIPP (Bechtel National, Inc. 1979) were based on a system of four shafts comprising

- a waste-handling shaft,
- a construction exhaust and salt-handling shaft,
- a storage exhaust shaft, and
- a ventilation supply and service shaft.

Subsequently, as part of a cost reduction program (U.S. Department of Energy 1982), the number of shafts was reduced to three, comprising

- a waste shaft,
- a construction and salt-handling shaft, and
- an exhaust shaft.

This change has profound effects on repository construction and operation and on costs.

The four-shaft system allowed for complete separation between construction and storage. Each of these two operations was planned to proceed independently of the other and concurrently, except for ventilation supply through a common shaft. This concept provided an exceptional degree of flexibility, redundancy, and safety. However, the rates at which waste is expected to become available for disposal at the WIPP site are very low in relation to the rates at which excavations can be made and waste can be emplaced in a four-shaft repository. Therefore, four shafts can be justified only insofar as they may be needed to provide the degrees of redundancy and safety required for nuclear facilities.

The three-shaft system interlinks construction and storage operations in many ways. It involves cyclical and sequential operations on two shifts a day: One shift is for construction and the other is for storage, but each does provide ample opportunity for the projected rates of excavation and disposal. To operate on either shift in the three-shaft system, the ventilation subsystems in both the construction and the storage areas must work.

Electrical power to back up the 32-km-long high-voltage line from the substation to the WIPP site has been reduced to one manually operated 800-kW diesel generator, from two automatic 2,500-kW diesel generators sufficient to operate the man hoist and one fan.

In general, although the three-shaft system appears to be functionally adequate, it does not include the degree of redundancy that is common in nuclear industry practice.

As a result of the design changes the WIPP SAR has required extensive revision. As of the end of 1983, six amendments had been issued. The FEIS, issued in 1980, however, is badly out of date. While the environmental impact of the new facility design may not be significantly different from that of the original design, the FEIS should be reissued to correspond with the present design.

CONCLUSIONS

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 45).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 45).

o Recently, the repository design has changed from four to three shafts. Although the three-shaft design appears to be functionally adequate, it does not possess the flexibility and redundancy of the four-shaft design (p. 49).

RECOMMENDATIONS

o Results from the Site and Preliminary Design Validation (SPDV) and in-situ experiments and information gathered during construction and development to final design must be incorporated with the final design of the WIPP repository (p. 44).

o Models should be used to assess whether or not closure of the excavations and consequent encapsulation of the waste in salt are likely to occur, and to determine the period of time within which they may occur (p. 48).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 48).

o The Final Environmental Impact Statement (U.S. Department of Energy 1980) should be reissued to correspond with the present design (p. 49).

CHAPTER SIX

PERFORMANCE ASSESSMENT

This chapter is based primarily on the panel's review of the WIPP Final Environmental Impact Statement (FEIS) (U.S. Department of Energy 1980), the Safety Analysis Report (SAR) (U.S. Department of Energy 1980-1983) and Modeling Verification Studies: Long-Term Waste Isolation Assessment (D'Appolonia Consulting Engineers, Inc. 1981). One of the main purposes of these documents was to estimate possible radiation exposure of both project employees and the general public. Such exposures could arise during preparation and loading of the waste at the originating facility, transportation of the waste to the repository site, and surface storage of waste at the WIPP site preparatory to emplacement, and also as a result of accidents that may occur during operation of the facility. In addition, there may be releases of radioactive material to the environment if the repository is breached at some future time.

While the panel has reviewed the plans for packaging the waste at the Idaho National Engineering Laboratory (INEL), a major source of TRU waste destined for WIPP, and transporting them to the WIPP site to determine how this affects the materials that will be emplaced in the repository, a detailed review of the consequences of routine and accidental events during these processes is beyond the scope of this study.

RELEASES AND OCCUPATIONAL DOSES DURING NORMAL OPERATION

Waste delivered by either rail or truck to the WIPP site will be unloaded and passed through airlocks to the waste-handling building. The handling procedures are described in detail in the FEIS and in the cost reduction proposals (U.S. Department of Energy 1982). A number of appropriately conservative assumptions are made as to the levels of contamination. For example, all waste packages are assumed to be contaminated to the maximum level of surface contamination permitted by U.S. Nuclear Regulatory Commission (NRC) and U.S. Department of Transportation (DOT) regulations. The total radioactivity that would be released to the environment from both surface and underground operations, from both residual surface contamination and leakage from damaged canisters of remotely handled waste, is estimated to be

0.004 Ci/yr. Throughout the analysis, the final dose estimates are upper limits.

The requirements of the FEIS for radiological impact analysis during normal operations could probably be discharged by simply noting that many years of experience with the handling of properly packaged waste provide assurance that necessary calculations can easily be made.

The annual occupational doses to workers at the WIPP facility from waste handling are estimated to reach an average of 0.9 rem for workers handling contact-handled waste and an average of 0.8 rem for workers with remotely handled waste. Although such doses, taken singly, are within permissible limits (5 rem), they may be too high for routine operations, because the same people may handle both types of waste, and other exposures from nonroutine events may occur.*

The results of rather straightforward dose calculations, based on a conservative set of assumptions, show that for environmental releases during normal operations, an individual at the closest point of habitation would receive a maximum dose (to the bone) of 0.007 percent of that received from natural radioactivity; and the whole-body dose would be less than 0.0002 percent of background (U.S. Department of Energy 1980, p. 9-30).

ACCIDENTAL RELEASES DURING OPERATION OF THE FACILITY

Accidents that may occur in the course of handling the radioactive waste will have a potential for exposure to both the employees and nearby inhabitants. The consequences of a waste-handling accident are examined by analysis of a number of scenarios ranging from a vehicle collision in the receiving area (no radioactive material released) to various failures of the drums and canisters from collisions, drops down mine shafts, spontaneous combustion, and external fires. The radiation doses are calculated in the conventional manner from estimates of the quantities of radioactivity released, the atmospheric concentration at a given location per unit of radioactivity released based on meteorological observations at the site, and measured population distributions.

The worst case described in the SAR (U.S. Department of Energy 1980-1983) for contact-handled TRU waste involves an underground fire, in which case the maximum 50-year bone-dose commitment offsite is estimated to be about 450 mrem. For either remotely handled TRU or experimental high-level waste, the worst case would be a hoist failure in which a container is dropped down the waste shaft. In these cases, the maximum bone-dose commitment to an off-site individual is calculated to be 24 mrem for the RH TRU accident and 49 mrem for the experimental high-level waste case. The maximum dose commitment to a worker from an accident is calculated to be 33 rem to the bone from an underground fire.

*DOE notes that exposures will be administratively monitored to assure that no individual exceeds 1 rem/yr from routine operations.

REPOSITORY BREACH SCENARIOS

For breach of the repository and effects upon the biosphere, there must be (1) an event to breach the repository, (2) a mechanism to bring the waste out of the repository, and (3) a place at a lower fluid potential energy level than that of the repository (water flows downhill) to which the water can move. Without all three conditions, movement to the biosphere will not occur. In a number of the scenarios considered in the FEIS (U.S. Department of Energy 1980, pp. 9-131ff), not all of the above conditions are fulfilled. Some of the scenarios have been and are being updated and augmented in the SAR. Calculations were carried out to determine the consequences of the sometimes implausible events. Finally, the studies were consequence analyses rather than risk analyses (i.e., the consequences of certain events are evaluated without regard to their likelihood). This methodology is particularly useful if the consequences are then found to be so small that the frequency of the event is not material. In all cases, the waste material is assumed to dissolve congruently with the salt, i.e., at the same rate as the salt.

The first scenario in the FEIS assumes a connection between the Rustler and Bell Canyon formations (of the Delaware Mountain Group) through the repository with flow upward and out of the Rustler into the Pecos River at Malaga Bend (see Figure 6-1). Though the flow may actually be in the opposite direction, this is a safe assumption because the transmissivity and hydraulic conductivity of the Rustler are orders of magnitude greater than those properties in the Bell Canyon (i.e., greater flows and shorter residence times (U.S. Department of Energy 1980)). The Magenta and Culebra Members of the Rustler are treated as a single unit.*

The second scenario assumes flow of dilute brine through a drill pipe from the Rustler through the repository and saturated flow back to the Rustler and to Malaga Bend. The driving force for this scenario appears to be lacking because the unsaturated water (8,000 ppm salt) flow does not appear to have the potential to push the saturated (400,000 ppm salt) flow out of the repository (see Figure 6-2).

The third scenario allows communication of the total waste storage horizon with the Rustler, but with no flow through the repository (i.e., the transfer is by diffusion only). Then, the flow is through the Rustler to Malaga Bend (see Figure 6-3).

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*More recent data allow analyses for movement through the Magenta and Culebra, the individual beds of the Rustler Formation, as well as the Rustler-Salado interface. Calculations by Barr et al. (1983) using these more recent data yield fluid travel times in excess of 130,000 years to a point 8 mi south of the center of the site, as compared to the 11 "bounding and conservative" FEIS calculations of about 3,600 years to a point 23 mi distant. Data collected since issuance of the FEIS and analysis of the breach events presented in the SAR allow depiction of distinct potentiometric maps for the three aquifers (Gonzalez 1983a,b; Mercer 1983).

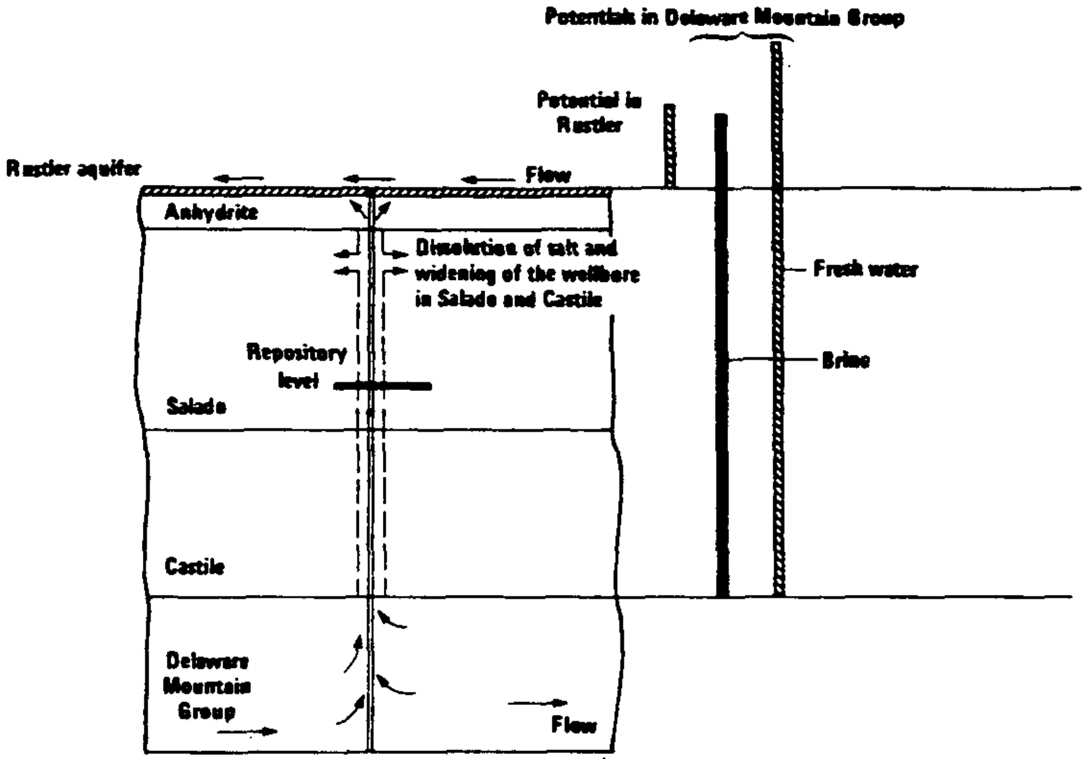


FIGURE 6-1 Schematic representation of scenario 1. Source: U.S. Department of Energy (1980).

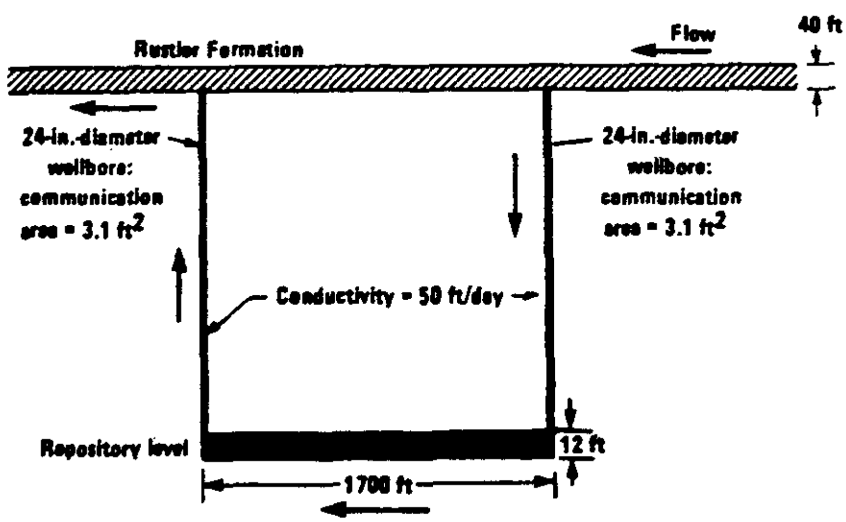


FIGURE 6-2 Schematic representation of scenario 2. Source: U.S. Department of Energy (1980).

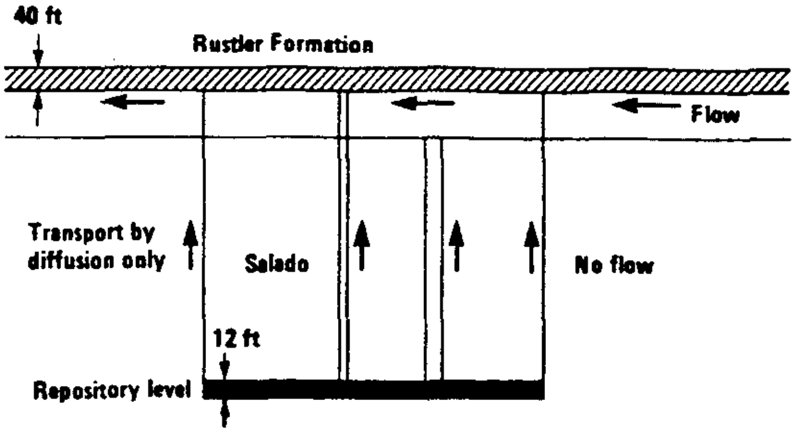


FIGURE 6-3 Schematic representation of scenario 3. Source: U.S. Department of Energy (1980).

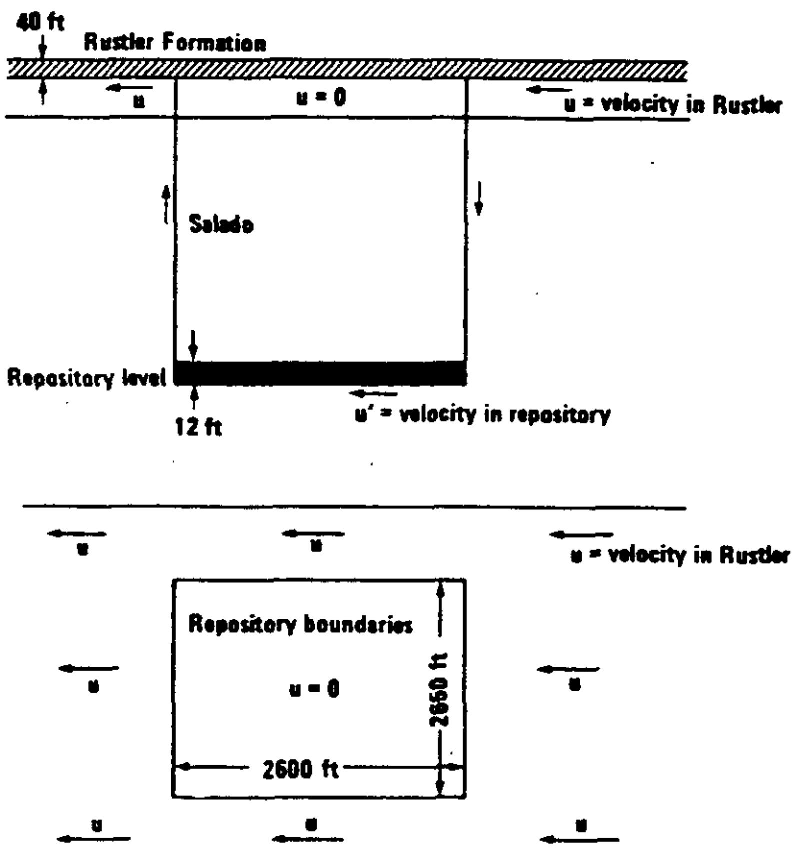


FIGURE 6-4 Schematic representation of scenario 4, showing the bounding condition (top) and velocities in the Rustler during the bounding condition (bottom). Source: U.S. Department of Energy (1980).

The fourth scenario allows the total flow of the Rustler above the waste repository to flow through the repository and then back to the Rustler and out to the Pecos River at Malaga Bend (see Figure 6-4).

The fifth scenario deals with drilling into the waste repository and, in particular, with the dose to the drill crews. Bingham and Barr (1979) estimated the probabilities of breaching the repository salt formation by inadvertent drilling in the distant future.

Recent analyses (Channell 1982, Bard 1982, Woolfolk 1982) have predicted the probability and consequence of a pressurized-brine pocket below the repository with subsequent release to the ground surface (see Figure 6-5).

The consequences of drilling and using a water well near the site have also been evaluated (U.S. Department of Energy 1980-1983, Spiegler 1981).

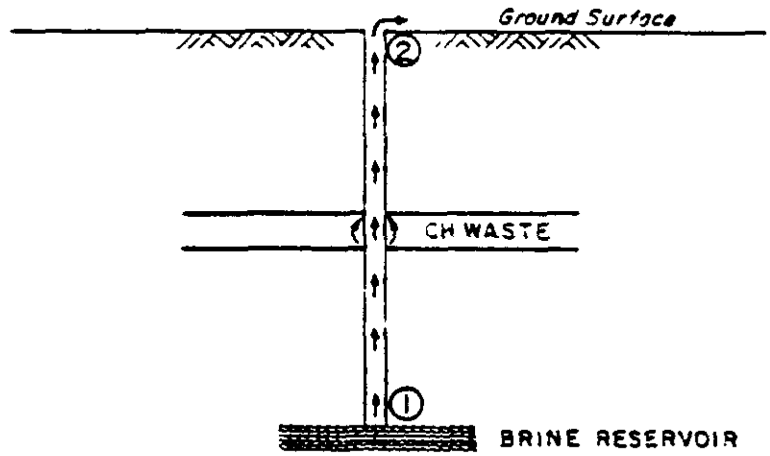
Though solution mining undoubtedly will be prohibited at the waste site, the consequences of this type of mining would be more severe than the liquid breach scenarios but less severe than the drilling scenario considered in the FEIS and SAR as shown by the EEG report (Little 1982) for the maximally exposed individual. The population dose due to solution mining is much greater.

Water flow times in the Rustler Formation from above the WIPP site to the Pecos River at Malaga Bend are calculated from models of flow through porous media to range from 5,000 to 100,000 years based upon point measurements.* For the consequence analyses, the shorter flow times are used together with the shortest distance between the site and Malaga Bend. The actual flow paths may be substantially longer, particularly for the Culebra where there is some indication of an arcuate route to the Pecos. Substantially shorter flow times, 1,850 years, have also been postulated (D'Appolonia Consulting Engineers, Inc. 1981).**

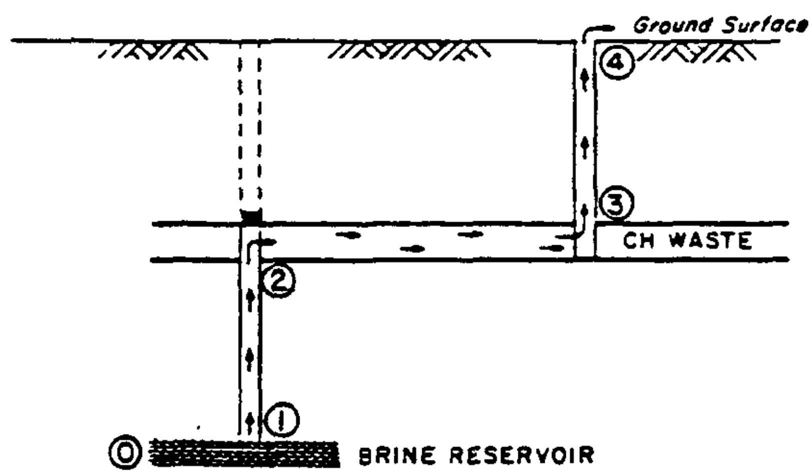
The sorption data listed in Appendix K-20 of the FEIS (U.S. Department of Energy 1980) were derived from more than one source. It is not clear to what extent these data are applicable to the geochemistry of the Rustler Formation and to sorption from solutions containing appreciable concentrations of dissolved salt. Furthermore, under actual conditions, precipitation may be more important than

*Analyses of the data in the Barr et al. (1983) report indicate that for the distances affected by pumping the wells (point measurements), drawdown values fit a porous medium model better than a fracture model. Mercer (1983), however, believed that the flow is through fractures through the porous media. The Barr assumption is satisfactory because the dolomite is thin and the fractures closely spaced, at least where halite still remains below the Culebra aquifer.

**Since the previously noted studies were conducted, studies of fluid movement in the Rustler have continued to allow refinement of knowledge of the regional hydraulics over an area larger than within the site boundaries. These studies led to development of a more up-to-date flow model for the Rustler (Barr et al. 1983). As additional hydrological data on the Rustler are collected, this model will be modified appropriately.



A. SINGLE BOREHOLE



B. FIRST BOREHOLE CONNECTING BRINE RESERVOIR TO CH WASTE, SECOND BOREHOLE CONNECTING CH WASTE TO GROUND SURFACE

FIGURE 6-5 Schematic representation of scenario involving a brine reservoir below the repository and release to the ground surface. Source: Case et al. (1982).

sorption. These uncertainties affect the estimated doses from radium-226. No discussion of the effects of such sorption uncertainties has been found in the FEIS.

Using the porous-medium model, the dissolution and transport processes take over 5,000 years for even the nonsorbing radionuclides and far longer for the sorbing species. Even considering waste containing fission products, this gives ample time for strontium-90 and cesium-137 to decay without the additional delaying effect of sorption. Sorption by the dolomite delays the release of the transuranics, although some of their more toxic decay daughters, such as radium-226, contribute later to doses to man (U.S. Department of Energy 1980, p. 9-139).

The dosages (50-year commitment) to the maximally exposed individual (as well as the dose to the maximally exposed worker in the drilling scenario) from each of these scenarios are given in Table 6-1. These doses were computed on the basis of International Commission on Radiological Protection (ICRP) reports ICRP-2 and ICRP-6. The revised permissible limits for neptunium-237 of ICRP-30 were not factored into these calculations. However, analysis of the dose calculations indicates that the portion of dose contributed by neptunium-237 is substantially less than one two-hundredths of the total and, therefore, will have no effect on the dose numbers in Table 6-1.

The nuclide releases from the two brine-repository scenarios were compared with the proposed release limits for plutonium-239, plutonium-240, and americium-241 in EPA's proposed rule on 40 CFR 191 (U.S. Environmental Protection Agency 1982). If one assumes that such releases are very unlikely, then all are at least a factor of 20 below their release limits. If the event results in "reasonably foreseeable releases," then the americium-241 is a factor of 2 less than the permissible amount and plutonium-239 and plutonium-240 are less than the permissible amounts by factors of approximately 3 and 10, respectively.

The doses are calculated based upon very long transport times ranging from 1,200,000 to 1,400,000 years for the time for the peak concentrations to reach Malaga Bend (U.S. Department of Energy 1980, Table 9-60).

The scenarios selected in the FEIS would appear to be the bounding cases. Apart from the implausible mechanisms for water intruding into the repository and returning to the Rustler aquifer, the assumptions in each step of the analysis tend to exaggerate the dose estimates. For example, the waste is assumed to dissolve as rapidly as salt; no solubility limits for the waste material and for its radionuclides are considered. Finally, no allowance is made for the fact that the radionuclides emerge into the Pecos River, the water of which is currently not potable because of high salinity. The water is not consumed by man or beast, and the river does not support a significant population of fish or shellfish. Even for these bounding cases, the dosages are so small that it is not worthwhile to consider more plausible cases. Confidence in the accuracy of these calculations of low dosages is strengthened by the independent calculations carried out by the EEG on transportation accidents, breccia pipe release mechanisms, withdrawal through wells, transport induced by pressurized-brine

TABLE 6-1 Fifty-Year Dose Commitments for Maximally Exposed Individual from Bounding Scenarios of Breaches of the WIPP Repository (mrem)

Scenario	Whole Body	Lung	Bone
Bell Canyon to Rustler	1.1×10^{-2}	--	2.1×10^{-2}
Restricted Rustler to Rustler flow	8.3×10^{-3}	--	1.6×10^{-2}
Diffusion flow to the Rustler	2.1×10^{-6}	--	4.2×10^{-6}
Unrestricted Rustler to Rustler flow	1.5×10^{-2}	1.2×10^{-5}	2.6×10^{-2}
Local well (Bell Canyon to Rustler)	1.3	--	1.7
Drill into repository	6.1×10^{-3}	2.1×10^{-2}	1.1×10^{-2}
Drill crew member	2.2×10^{1}	--	--
Pressurized brine[a] reservoir flow to the surface	5.6×10^{2}	2.2×10^{3}	9.8×10^{2}
Worker	2.8×10^{2}	1.1×10^{3}	4.9×10^{2}
Solution mining of halite	7.2×10^{1}	--	--
Natural background	5×10^{3}	9×10^{3}	5×10^{3}

[a]Calculated using recommendations of ICRP-26 and ICRP-30. All others calculated using recommendations of ICRP-30.

SOURCE: U.S. Department of Energy (1980, 1980-1983), Little (1982).

reservoirs, and long-term release scenarios. The dose commitments calculated by the EEG are similar to those shown in the FEIS, SAR, and brine reservoir report (Channell 1982).

Questions have been raised about the possibilities of reducing the time of travel of these higher-water-velocity flow paths by fractures or karst-type openings, but seem to have been answered in part in the Barr et al. (1983) publication. As is well known, such studies cannot prove the existence or nonexistence of karst-type flow within the region sampled. It is very difficult to prove that no connected fracture flow exists or is likely to exist. The problem might be bounded by computing the total water flow and flow rate through the aquifers above the WIPP site and, using the solubility limits of the individual nuclides, calculating the maximum amount of radioactive material that could be put into solution and transported to the Pecos.

CONCLUSIONS

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (p. 52).

o The long-term release scenarios, shown in Figures 6-1 to 6-6, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within permissible limits for the general population (170 mrem whole body) and far below the dosages from normal background radiation (average over 50 years of 5,000 mrem) (p. 58). Further analyses will be needed to conform to the Environmental Protection Agency (EPA) requirements.

RECOMMENDATIONS

o Though karst-type flow in the strata above the salt beds (the Rustler Formation) is known to occur near Nash Draw several kilometers to the west, the extent to which it reaches eastward is not delineated clearly. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be reduced sharply. The probability of such flows, their degree of development east of the Pecos River, and the effect of such flows upon radiation dosages need to be determined (pp. 58-60).

o For consistency, and to permit direct comparison among all the modes of release, all dosages should be calculated on the same basis (i.e., if recommendations of ICRP-26 and ICRP-30 were used rather than those of ICRP-2) (pp. 58-59).

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GLOSSARY

activity	A measure of the rate at which a material emits nuclear radiation, usually given in terms of the number of nuclear disintegrations occurring in a given length of time. The unit of activity used in this document is the curie (Ci).
anhydrite	A mineral consisting of anhydrous calcium sulfate: $CaSO_4$. It is gypsum without its water of hydration and is denser, harder, and less soluble than gypsum.
anticline	A fold of rocks whose core contains the stratigraphically older rocks; it is convex upward.
aquifer	A body of rock that contains enough saturated permeable material to transmit groundwater and to yield significant quantities of groundwater to wells and springs. The opposite of an aquiclude.
argillaceous rocks	Rocks, especially shale, containing appreciable amounts of clay.
artesian	Refers to water confined underground under pressure so that it will rise in a well. Sometimes the word is used to mean that the water flows out at the surface, but that, strictly speaking, is "flowing artesian."
background radiation	Radiation in the human environment from naturally occurring elements, from cosmic radiation, and from fallout.
bedded salt	Consolidated layered salt separated from other layers by distinguishable planes of separation.
Bell Canyon Formation	A sequence of rock strata that forms the topmost unit of the Delaware Mountain Group.

biotransport (biosphere transport)	Movement of radionuclides through the biosphere, as in food chains. Used in contrast to geotransport.
breccia pipe	As used in this report, a vertical geologic structure composed of angular broken rock fragments, in a fine-grained matrix or held together by a mineral cement; formed by the collapse of rock overlying an opening, as by foundering of the roof of a cave.
brine aquifer	Same as shallow-dissolution zone.
brine inclusion	A small opening in a rock mass (salt) containing brine; also, the brine included in such an opening. Some gas is often present.
canister	As used in this report, a container, usually cylindrical, for remotely handled waste, spent fuel, or high-level waste. The waste will remain in this canister during and after burial. A canister affords physical containment but not shielding; shielding is provided during shipment by a cask.
Capitan Reef	A buried fossil limestone reef of Permian age that rings the Delaware Basin except in the south.
Carlsbad Potash District	The area east of Carlsbad and north and west of the Los Medanos site formally designated by the U.S. Geological Survey as having potentially economic grades of potash mineralization.
Castile Formation	A formation of evaporite rocks (interbedded halite and anhydrite) of Permian age that immediately underlies the Salado Formation in which the WIPP repository will be located.
characterization, site	The process of making geologic and environmental studies to identify potential sites for mined geologic repositories. Detailed site characterization goes further: all additional data are collected that would be necessary if a license application is to be submitted.
clastic rock	Rock made up of broken fragments of preexisting rocks.

complexation — The formation of a molecular or ionic complex, usually between an inorganic ion such as uranium or plutonium and a larger organic molecule. Such complexes are often quite stable and have chemical and physical properties, such as solubility and chemical reactivity, that are different from their components.

conservative — When used with predictions or estimates, leaning on the side of pessimism. A conservative estimate is one in which the uncertain inputs are used in the way that maximizes the impact.

contact-handled waste — Waste that does not require shielding other than that provided by its container.

containment — The retention of radioactivity within prescribed boundaries, such as within a waste package. In this document, usually retention within a system to the exclusion of its release to the biosphere in unacceptable quantities or concentrations.

contamination — Undesirable radioactive material present on outside surfaces. This contamination can be either transferable or fixed. Radiation penetrating the walls of a waste package from within is not contamination.

control zones — Areas of land around the WIPP site whose use is governed by controls and restrictions.

creep closure — Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.

crystalline rock — Rock designated as being either igneous or metamorphic, not sedimentary; rock consisting wholly of mineral crystals or fragments of crystals.

Culebra dolomite — The lower of two layers of dolomite within the Rustler Formation that are locally water bearing.

decay, radioactive — The decrease in the number of radioactive nuclei present in a radioactive material due to their spontaneous transmutation. Also, the transmutation of a radionuclide into another nuclide by the emission of a charged particle.

decontamination	The removal of unwanted material (especially radioactive material) from the surface or from within another material.
defense waste	Nuclear waste deriving from the manufacture of nuclear weapons and the operation of naval reactors. Associated activities such as the research carried on in the weapons laboratories also produce defense waste.
deformation front	Boundary of a zone of folding, faulting, shearing compression, or extension of the rocks as a result of various Earth forces.
Delaware Basin	An area in southeastern New Mexico and adjacent parts of Texas where a sea deposited large thicknesses of evaporites some 200 million years ago. It is partially surrounded by the Capitan Reef.
Delaware Mountain Group	A set of three formations that underlie the Castile Formation at the Los Medanos site. The uppermost of these is the water-bearing Bell Canyon Formation.
direct-access scenario	A postulated sequence of events in which radionuclides are carried directly to the surface, such as by means of drilling.
discharge point or area	In groundwater hydraulics, the point (or area) where water comes out of an aquifer onto the surface.
disposal	Permanent disposition of waste in a repository. Use of the word "disposal" implies that no need for later retrieval is expected.
dissolution	The process whereby a space or cavity in or between rocks is formed by the solution of part of the rock material.
dissolution front	The boundary of a geologic region within which rock is dissolving. In this document, the term particularly refers to the wedgelike leading edge of salt dissolution at the interface between the Rustler and the Salado formations.
distribution coefficient	In an aquifer, the ratio of the concentration of a substance sorbed by the rock to the concentration of the substance remaining in solution. A large distribution coefficient implies that the substance moves much more slowly than the groundwater. It is measured in units of cm^3/g or equivalent.

dolomite	A sedimentary rock consisting mostly of the mineral dolomite: $CaMg(CO_3)_2$. It is commonly found with limestone.
dome (breccia pipe)	A type of hill found near the Los Medanos site; under at least some of these hills lies a roughly cylindrical volume of breccia (rock reconstituted from coarse rock fragments).
dose equivalent commitment	The total dose equivalent that results from an intake of radioactive materials during all the time from the intake to the death of the organism. For people, the dose is usually evaluated for a period of 50 years from the intake. Units are man-rems. Less formally, dose commitment.
dose (radiation)	A general term indicating the amount of energy absorbed per unit mass from incident radiation.
dose rate	The rate at which dose is delivered.
drift	A horizontal mine passageway.
evaporite	A sedimentary rock composed primarily of minerals produced by precipitation from a solution that has become concentrated by the evaporation of a solvent, especially salts deposited from a restricted or enclosed body of seawater or from the water of a salt lake. In addition to halite (NaCl), these salts include potassium, calcium, and magnesium chlorides and sulfates.
fault	A surface or zone of rock fracture along which there has been displacement.
fluid inclusion	Brine inclusion. An opening in a rock mass (salt) containing brine; also the brine included in such an opening. Some gas is often also present.
formation (geologic)	The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock (usually sedimentary) generally characterized by some degree of internal lithologic homogeneity or distinctive features.
geotransport	In this report, movement of radionuclides through subsurface soils and rocks, especially movement with the groundwater. Used in contrast to biotransport.

gypsum — A soft and, when pure, white mineral consisting of hydrous calcium sulfate:

$$CaSO_4 \cdot 2H_2O.$$

half-life — The time required for the activity of a group of identical radioactive nuclei to decay to half its initial value.

halite — The mineral rock salt: NaCl.

high-level waste — Radioactive waste resulting from the reprocessing of spent fuel. Discarded, unreprocessed spent fuel is also high-level waste. It is characterized by intense, penetrating radiation and by high heat-generation rates. Even in protective canisters, high-level waste must be handled remotely.

high-standard resources — Potash mineralization of 8 percent K_2O as langbeinite, or 14 percent K_2O as sylvite, or equivalent grade of mixed langbeinite-sylvite occurring in a minimum 4-foot interval. Roughly equivalent to the grade of ores currently being mined in the Carlsbad district.

horizon — In this report, an underground level. For instance, the waste-emplacement horizon in the WIPP is the level about 650 m deep at which openings would be mined for waste disposal.

hydraulic conductivity — A quantity defined in the study of groundwater hydraulics that describes the rate at which water flows through an aquifer. It is measured in feet per day or equivalent units. It is equal to the hydraulic transmissivity divided by the thickness of the aquifer.

hydraulic gradient — A quantity defined in the study of groundwater hydraulics that describes the rate of change of head with distance of flow.

hydraulic potential (hydraulic head) — Hydraulic pressure corrected for the potential energy of elevation. In an aquifer it is equivalent to the highest level of a column of water that the pressure in the aquifer will support. It is measured relative to a specified level, in this document, sea level.

hydraulic transmissivity A quantity defined in the study of groundwater hydraulics that describes the rate at which water may be transmitted through an aquifer.

hydraulic transport The transport of dissolved substances by groundwater.

hydraulics, hydrology These two terms tend to be used interchangeably, but they do not mean quite the same thing. Hydraulics is an engineering discipline; hydrology is the related science. Hydraulics deals with the flow of water. Hydrology deals with water: its properties, circulation, and distribution, from the time it falls as rainwater until it is returned to the atmosphere through evapotranspiration or flows into the ocean.

hydrologic modeling The process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of groundwater and the movement of dissolved substances.

in situ In the natural or original position. Used in this document to distinguish in-place experiments, rock properties, and so on, from those in the laboratory.

interstitial brine Brine distributed in very small openings throughout a salt mass.

ion exchange A phenomenon in which chemical species in one phase or material exchange with similar species in another phase.

irradiation Exposure to any form of radiant energy.

isotope A species of atom characterized by the number of protons and the number of neutrons in its nucleus. In most instances an element can exist as any of several isotopes, differing in the number of neutrons but not in the number of protons in their nuclei. Isotopes can be either stable or radioactive. The latter are called radioisotopes or radionuclides.

karst A type of topography that is formed on limestone, gypsum, and other rocks by dissolution; characterized by sinkholes, caves, and underground drainage.

langbeinite	A mineral, $K_2Mg_2(SO_4)_3$, used in the fertilizer industry as a source of potassium sulfate.
leaching	The process of extracting a soluble component from a solid by the percolation of a solvent (in this report, water) through the solid.
lease-standard resources	Potash mineralization of 4 percent K_2O as langbeinite, or 10 percent K_2O as sylvite, or equivalent grade of mixed langbeinite-sylvite occurring in a minimum 4-foot interval. If located on federal land, can be acquired only through competitive bid.
liquid-breach scenario	A postulated sequence of events in which radionuclides are carried by groundwater and released.
lithostatic pressure	Subsurface pressure due to the weight of overlying rock or soil.
Los Medanos	In this report, the area in southeastern New Mexico surrounding the site proposed for the WIPP repository of alternative 2. In Spanish it means "dune country," and has a tilde over the n: Los Medaños.
low-level waste	Any gaseous, liquid, or solid radioactive waste not classified as high-level waste, TRU waste, spent nuclear fuel, or byproduct material.
Magenta dolomite	The upper of two layers of dolomite within the Rustler Formation that are locally water-bearing.
Malaga Bend	A sharp bend in the Pecos River 20 miles southeast of Carlsbad, New Mexico, and directly east of the town of Malaga. The discharge points of the Rustler aquifers are a series of brine seeps and springs nearby.
man-rem	A unit of population dose.
maximally exposed person	A hypothetical person who is exposed to a release of radioactivity in such a way that he or she receives the maximum possible individual dose or dose commitment. For instance, if the release is a puff of contaminated air, this is a person at the point of largest ground-level concentration who stays there during the whole time of cloud passage. The use of this term is not meant to

imply that there really is such a person, but only that thought is being given to the maximum exposure a person could receive.

maximum — The highest dose delivered to the whole body or to an individual dose individual organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed person, is one whose location and activities maximize the dose.

Nash Draw — A shallow 5-mile-wide valley open to the southwest located to the west of the WIPP reference site.

natural background radiation — Radiation in the human environment from naturally occurring elements and from cosmic radiation.

nuclide — Isotope.

overcoring — A process for removing waste from its burial in salt by extracting a cylinder of salt that surrounds and contains the waste.

overpack — A container put around another container. In the WIPP, overpacks would be used on damaged or otherwise contaminated drums, boxes, and canisters that would not be practical to decontaminate.

packer — A device used in drilled holes to isolate geological strata from one another in order to carry out hydrologic studies of particular formations.

Paradox Basin — A 10,000-square-mile area in southeastern Utah and southwestern Colorado underlain by a series of salt-core anticlines.

permeability — Equivalent to hydraulic conductivity.

Permian Basin — A region in the central United States where, during Permian times 280 to 225 million years ago, there were many shallow seas that laid down vast beds of evaporites. The Delaware Basin is a part of the Permian Basin.

polyhalite — An evaporite mineral that is hard, poorly soluble, and with no economic value:

$$K_2MgCa_2(SO_4)_4 \cdot 2H_2O.$$

population dose The sum of the radiation doses received by the individual members of a population.

potash In this report, a potassium compound, especially as used in agriculture or industry.

potentiometric surface The surface of the hydraulic potentials of an aquifer. It is usually represented in figures as a contour map, each point in which tells how high the water would rise in a well tapping that aquifer at that point.

radiolysis Chemical decomposition by the action of radiation.

recharge point (or area) In groundwater hydraulics, the point (or area) where surface water enters an aquifer.

rem A unit of individual radiation dose equivalent.

remotely handled waste Waste that requires shielding in addition to that provided by its container in order to protect people nearby.

repository A facility for the storage or disposal of radioactive waste.

reprocessing The process by which spent fuel from a reactor is separated into waste material and uranium and plutonium to be reused as nuclear fuel.

reserves Mineral resources that can be extracted profitably by existing techniques and under present economic conditions.

resources Reserves plus all other mineral deposits that may eventually become available--either known deposits that are not economically or technologically recoverable at present, or deposits that may be inferred to exist but have not yet been discovered.

retrievable Describes storage of radioactive waste in a manner designed for recovery without loss of control or release of radioactivity.

risk The product of probability and consequence. In this report, the radioactive risk of a scenario is the population dose resulting from that scenario multiplied by the probability that the scenario will actually occur.

Rustler Formation	The evaporite beds, including mudstones, of probable Permian age that immediately overlie the Salado Formation in which the WIPP disposal levels may be built.
Salado Formation	The evaporite formation of Permian age within which wastes would be disposed of in the WIPP repository of alternative 2.
Salt Vault, Project	A field experiment carried out by ORNL between 1965 and 1967 in an abandoned salt mine at Lyons, Kansas. Its purpose was to demonstrate the feasibility and safety of the concept of emplacing high-level waste in salt, to demonstrate equipment and techniques for handling packages of highly radioactive solids, and to secure data for the design of an actual disposal facility. Its results are reported in Bradshaw and McClain (1971).
San Simon Sink	The central, most depressed area of San Simon Swale.
San Simon Swale	A broad depression about 15 miles east of the Los Medanos site, open to the southeast.
scenario	A particular chain of hypothetical circumstances that could, in principle, release radioactivity from a repository.
shaft	A man-made hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine or a repository.
shallow-dissolution zone	Also called a brine aquifer. A zone of residual material at the interface of the Rustler and Salado formations left after dissolution of the original salt. It is highly permeable and contains much brine.
sorption	The binding of one substance to another on a microscopic scale, such as by adsorption or ion exchange. In this report, the word is used especially with reference to the sorption of solutes onto aquifer solids.
spent fuel	Nuclear-reactor fuel that, through nuclear reactions, has been sufficiently depleted of fissile material to require its removal from the reactor.

storage	Temporary disposition in a repository. Use of the word storage implies keeping open the possibility of retrieving the waste for reprocessing, for moving it elsewhere, etc. Storage usually implies the need for continued surveillance.
sylvite	A mineral, KCl, used as a fertilizer.
tectonic activity	Movement of the Earth's crust such as uplift and subsidence and the associated folding, faulting, and seismicity.
thermal gradient	The rate of change of temperature in the direction of increasing temperature.
transuranic nuclide	A nuclide with an atomic number greater than that of uranium (92). All transuranic nuclides are produced artificially and are radioactive.
TRU waste	Waste with a specific transuranic alpha activity of 100 nCi/g or greater. This waste can vary greatly in its specific gamma activity.

ABBREVIATIONS AND ACRONYMS

AEC	U.S. Atomic Energy Commission
CH	Contact-Handled
DOE	U.S. Department of Energy
DEIS	Draft Environmental Impact Statement
DHLW	Defense High-Level Waste
DMG	Delaware Mountain Group
DOT	U.S. Department of Transportation
EEG	State of New Mexico Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
FEIS	Final Environmental Impact Statement
HEPA	High-Efficiency Particulate Air (a type of filter)
ICRP	International Commission on Radiological Protection
INEL	Idaho National Engineering Laboratory
IRG	Interagency Review Group
NRC	U.S. Nuclear Regulatory Commission
PREPP	Process Experimental Pilot Plant
R&D	Research and Development
RH	Remotely Handled

RSE	Radiation Source Experiment
SAR	Safety Analysis Report
SPDV	Site and Preliminary Design Validation
SWEPP	Stored Waste Experimental Pilot Plant
TE	Technology Experiment
TRU	Transuranic (refers to nuclides beyond uranium in the periodic table)
TRUPACT	Transuranic Package Transporter
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

APPENDIX A

LETTER REPORT, PARKER TO GLOYNA, May 1, 1979

NATIONAL RESEARCH COUNCIL

COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 18, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
Department of Energy (MS B-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter report by the Panel on the Waste Isolation Pilot Plant (WIPP) on its review of the WIPP Draft Site Characterization Report (SAND 78-1596). The Committee on Radioactive Waste Management has discussed the substance of this letter and endorses the views of the Panel expressed therein.

I hope these observations will be useful in the continuing process of geotechnical characterization of the proposed WIPP site.

Sincerely,

Earnest F. Gloyna
Chairman

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 1, 1979

Dr. Earnest F. Gloyna, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dear Dr. Gloyna:

As part of its continuing responsibility to review criteria and guidelines for the location, design, construction, and operation of a proposed radioactive waste isolation pilot plant (WIPP), this Panel has reviewed the WIPP Draft Site Characterization Report (DSCR), SAND 78-1596, prepared by Sandia Laboratories for the Department of Energy. The DSCR, which has subsequently been published, with the same report number, as "Geological Characterization Report (WIPP)," is a compilation of the known geotechnical information about the proposed site and the surrounding region, with chapters devoted to regional geology, site geology, seismology, hydrology, geochemistry, resources, and special studies of WIPP repository rocks. It does not address such matters as socioeconomic considerations, accessibility, transportation and failure modes, which will need to be included in a complete site characterization.

The following brief account, which must be viewed in conjunction with the DSCR itself, is intended for a very limited audience of readers fully conversant with the contents of the basic document.

As a first step in this review, individual chapters of the DSCR were examined in detail by subgroups of the Panel with special expertise in the disciplinary areas involved, after which their separate comments were discussed by the full Panel in a meeting with the Sandia authors of the document.

The Panel then reviewed the extent to which the information contained in the DSCR provides sound geotechnical support for an environmental impact analysis and related decisions leading to the selection of an appropriate site for the proposed pilot plant. The review focused on the Report's exposition of geotechnical information with critical bearing on the site's probable ability to provide the desired long-term isolation of emplaced waste, e.g. seismic or tectonic uplift, intrusion of ground-water, thermal and mechanical characteristics of the host rock, and retardation effects along possible migration pathways. The Report did not treat, nor did the Panel consider, the effect of the emplacement of waste or the waste itself on the long term integrity of the repository. Although recognizing the considerable coverage and detail of the information presented, the Panel noted a few areas where additional data are desirable to more fully characterize the geotechnical aspects of the area under consideration. These include the following:

a) A major disagreement between conclusions reached in the DSCR and the views of R. Y. Anderson is mentioned in several places. Anderson, a professor of geology at the University of New Mexico at Albuquerque, who has specialized in the study of evaporite deposits in the Delaware Basin, was commissioned by Sandia Laboratories to prepare a report on the deep dissolution of salt in the region around the proposed WIPP site. Basing his argument on a postulated unconformity at the base of the Salado formation and on his hypothesis that the so-called "breccia pipes" are localized features of deep dissolution which originated as collapse chambers in salt beds immediately overlying the reef and basin aquifers, Anderson suggested that dissolution may be so rapid that the entire salt formation will disappear within a million years. The DSCR, on the other hand, considers only dissolution at the western edge of the salt beds and concludes that present rates will ensure preservation of the Salado at the WIPP site for at least a few million years. The Panel feels that a more thorough explanation should have been provided as to why the authors of the DSCR consider their views preferable to Anderson's hypothesis. On this same issue of salt dissolution, the DSCR estimates of the rate of retreat of the solution front two or three miles west of the site are evidently based on the assumption of uniform dissolution over a wide area under average conditions. A rational basis should be provided for this assumption, vis a vis the possibility of accelerated dissolution rates in local areas, with selective removal of salt from beneath the present sedimentary cover, particularly if pluvial conditions were to change in the future.

b) Additional data and analyses would be helpful to determine with greater confidence the current rates of tectonic uplift in the region and whether, as a result, the salt may be exposed to accelerated erosion at some time in the foreseeable future.

c) The so-called "breccia pipes" need more detailed analyses to determine whether they may serve as conduits for water that may have promoted, or may in the future promote, deep dissolution of the salt beds.

d) There appears to be sufficient information to resolve the question regarding the likelihood of upward flow from the Bell Canyon formation through the Salado, where the proposed repository horizons are located, to the overlying Rustler. This should be addressed.

e) Because rock properties have a strong influence on mine design, more detailed information is needed on the various rock types in the area and on their permeability, fracture, and thermal properties under conditions as similar as possible to those that would be found in a repository. Both laboratory and field tests approximating in-situ conditions will be required to develop this information.

f) The information on sorption of the important radionuclides by materials to be expected in possible migration paths, under conditions resembling those near a possible repository, seems to be sparse. As soon as the types of waste to be stored in the repository are known, a more complete discussion should be presented of the retardation anticipated in the migration paths.

g) The most recent episode of any recrystallization in the Salado formation near the proposed WIPP site is reported to have occurred about 200 million years ago. The Panel urges confirmation of this important date by further studies and other techniques, as described in Section 7.8 of the DSCR.

In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objectives, criteria for safe operation, and waste forms to be accommodated.

Sincerely,

Frank L. Parker

Frank L. Parker, Chairman
Panel on the Waste Isolation
Pilot Plant

APPENDIX B

LETTER REPORT, PARKER TO WILSON, SEPTEMBER 10, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 12, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
U. S. Department of Energy (MSB-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter, by the Panel on the Waste Isolation Pilot Plant (WIPP), regarding the desirability of sinking an exploratory shaft at the proposed repository site. The Committee on Radioactive Waste Management has reviewed the letter and endorses the Panel's views expressed therein.

Sincerely,

E. Bright Wilson

E. Bright Wilson
Chairman
Committee on Radioactive
Waste Management

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 10, 1979

Dr. E. Bright Wilson, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Wilson:

During the past year, the Panel on the Waste Isolation Pilot Plant (WIPP) has become familiar with the findings of the various extensive geological explorations, including boreholes from the surface and attendant geotechnical studies, attempting to characterize the proposed WIPP site and provide a basis for judging this aspect of the site's suitability for a waste repository. This familiarization process has included briefings by representatives of Sandia Laboratories and the U. S. Geological Survey, study of both the published and unpublished technical literature, site visits, examination of actual borehole cores, and discussions with other experts in selected geotechnical areas.

Our efforts have brought to light no disqualifying results from these explorations and studies to rule out further consideration of the proposed site at this stage. The Panel has reached this conclusion after taking into account the comments made in my letter of May 1, 1979, reporting on our review of the WIPP Draft Site Characterization Report (issued as SAND78-1596, Geological Characterization Report), pointing out that certain effects have been observed which can be interpreted as indicating the possible existence of significant anomalies. Additional information is clearly required before these anomalies can be resolved

and a decision made regarding the adequacy of the proposed WIPP site for the construction of a repository. Furthermore, continued commitments to final details of repository design in the absence of additional site-specific information may be both misleading and wasteful.

The Panel is of the unanimous opinion that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and cannot resolve all the major remaining uncertainties. Accordingly, the Panel recommends that:

(1) An exploratory shaft be sunk at the site of one of the proposed access shafts as soon as practicable, to the depth of the proposed repository horizon.

(2) Drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

Development of the shaft, tunnels, and any other exploratory excavations should be consistent with applicable environmental and safety standards, strict quality assurance procedures, and should be compatible with an actual repository, if one is constructed at this site.

Sincerely,

Frank L. Parker

Frank L. Parker
Chairman, Panel on the
Waste Isolation Pilot Plant

APPENDIX C

CONTINUING EVALUATION OF THE CARLSBAD SITE, July 28, 1980

REPORT NO. DOE/CH/93023-1

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

(202) 389-6727

August 1, 1980

Ms. June Wiinikka
Contracts Management Office
U.S. Department of Energy
9800 South Cass Avenue
Argonne, IL 60439

Re: Task Agreement DE-AT02-76CH93023

Dear Ms. Wiinikka:

Enclosed are six (6) copies of a report prepared under the referenced Task Agreement, together with a completed DOE Form IR-427.

Sincerely,

John T. Holloway
Staff Officer
WIPP Panel

Report No. DOE/CH/93023-1

CONTINUING EVALUATION OF THE CARLSBAD SITE

A Report to the U. S. Department of Energy, prepared by the Panel on the Waste Isolation Pilot Plant of the Committee on Radioactive Waste Management.

COMMISSION ON NATURAL RESOURCES
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
July 28, 1980

N O T I C E

ABSTRACT

It is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements, set forth in his February 12, 1980, message to the Congress, for evaluation of this site as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

NOTICE: The project that is the subject of this report was authorized by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Such authorization reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

The report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee of the National Academy of Sciences.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

Funded by the U. S. Department of Energy
Contract No. EY-76-C-02 2708-023

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Staff Officer

NOTE: Two Panel members did not participate in the deliberations leading to this report; John W. Winchester was out of the country on sabbatical leave, and Karl P. Cohen is a new member of the Panel.

CONTINUING EVALUATION OF THE CARLSBAD SITE

The Panel on the Waste Isolation Pilot Plant (WIPP) was organized by the National Academy of Sciences in 1978, under the Committee on Radioactive Waste Management of the National Research Council, to review the scientific and technical criteria and guidelines for designing, constructing, and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere, with specific attention to a proposed site near Carlsbad, New Mexico.

On February 12, 1980, President Carter transmitted to the Congress "A Report on His Proposals for a Comprehensive Radioactive Waste Management Program." This report states the President's decision that the WIPP project, currently authorized for the unlicensed disposal of defense transuranic waste and for research and development using high-level defense waste, should be cancelled; but that the Carlsbad site will continue to be evaluated, along with other sites in other locations, for possible use as a licensed repository for defense and commercial high-level wastes.

The Panel has reviewed in depth the work of the DOE contractors on the geologic characteristics of the Carlsbad site, the characteristics of the defense and spent-fuel radioactive wastes that have been considered for emplacement, and the conceptual design of the repository. The WIPP Draft Environmental Impact Statement has been analyzed with

respect to the potential impact on public health and safety.

As a result of these deliberations, the Panel has previously concluded that continued investigation of the Carlsbad site is warranted and has recommended that the project proceed with an exploratory shaft to determine in greater detail the geologic, hydrologic, and structural features of the candidate salt beds, and with in-situ tests as necessary to evaluate the geotechnic adequacy of this site for a waste repository. The Panel considers these in-situ tests to be no less timely and technically desirable within the framework of the President's statement.

In connection with the Carlsbad site, a talented team of scientists and engineers has been assembled, and extensive geological exploration has been conducted. Laboratory facilities are excellent, important experiments on waste disposal are under way, and underground engineering designs have been developed. The project has gained momentum that would be difficult to recapture if it were to be interrupted. There are sound technical reasons for continuing the exploratory work:

1. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

   The analyses made thus far, supported by ongoing and planned testing programs to validate these analyses,

lead to the reasonable expectation that the site may be suitable not only for its original limited purpose as a defense transuranic waste repository but also as a licensed repository for both defense and commercial high-level and transuranic waste. The present experimental program will yield results that can be applied to the expanded purpose envisioned in the President's program. The exploratory shaft, now planned and ready to be constructed to a depth suitable for transuranic waste, can be extended to a lower horizon, where there is another salt bed that may be better suited for high-level wastes. The information obtained from this exploratory work will not only be useful for further evaluation of the Carlsbad site but can also be applied to other candidate salt formations.

2. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives.

Very long lead times are involved in the President's proposed new program of selecting alternative sites, constructing test facilities at each, choosing a first repository site, and eventually constructing one or more licensed repositories.

The extensive information already obtained on the Carlsbad site and the demonstrated expertise of the existing investigative teams provide an

opportunity to proceed much sooner with in-situ testing at a potential candidate site--a capability which will have to be developed before this or any other site can be selected for a first actual repository.

More is known about the Carlsbad site than about any of the other sites under consideration. Questions remain that will require resolution by additional analyses and testing, but such questions are normal for this stage of an investigation.

The Panel concludes that it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:

- o providing prototype experience in site qualification;
- o testing, in situ, performance assumptions about the geologic medium; and
- o developing techniques and information which will be required in the licensing process.

If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review.

APPENDIX D

NATURAL RESOURCES AT WIPP

The resources of concern are principally the potash salts, which are located in 11 ore zones from 126 m to 240 m above the repository depth, and potential hydrocarbon resources, which are well below the repository depth (see Table D-1). Other possible resources, such as salt, gypsum, and caliche, are considered of insufficient importance to warrant concern, as their abundance throughout the area is such that the withdrawal of this area would have no impact on their availability (Brausch et al. 1982).

Groundwater is not considered a resource at the WIPP site, because water in greater volume and of better quality is available from other areas nearby. Quality of water in the Los Medanos area is extremely variable; for example, total dissolved solids in water from the Magenta dolomite range from 5,460 to 270,000 ppm; in the Culebra dolomite from 3,200 to 420,000 ppm; and in the Bell Canyon Formation from 1,000 to more than 300,000 ppm (U.S. Department of Energy 1980-1983).

The originally proposed controlled-access area at the site, including Zones I, II, III, and IV, has recently been reduced by the elimination of most of Zone IV. The new site boundary encompasses a square area comprising 16 sections, as shown in Figure 2-4. This means that most of the former Zone IV is now open for exploitation of its mineral resources. Zone III provides a 1-mile-wide buffer zone between the repository excavations and the site boundary.

Within the time limits of repository control, no drilling for hydrocarbons and no mining for potash will be allowed within Zones I, II, and III. Since the hydrocarbon horizons are below the salt sequences, directional drilling from outside the new site boundary could be considered to explore for hydrocarbons. Potash mining might be permitted outside the site boundary. However, the panel believes that DOE should have the authority to review and approve each proposed drilling and recovery project in the former Zone IV in order to assure procedures consistent with repository integrity.

HYDROCARBONS

If directional drilling is used for hydrocarbon exploration and production, standard well techniques of casing, cementing, and

TABLE D-1 Significance of Resources and Reserves at the WIPP Site

Deposit	WIPP Site	Region	United States	World
		RESOURCES[a]		
Sylvite (at lease grade)				
Quantity, million tons ore	88.5	4,260	8,500	850,000
Percentage at WIPP site		2.1	1.0	0.010
High grade	54.0			
Low grade	133.2			
Langbeinite (at lease grade)				
Quantity, million tons ore	264.2	1,140	No estimate available	
Percentage at WIPP site		23 (21.5 as K_2O)		
High grade	77.6			
Low grade	351.0			
Crude Oil				
Quantity, million barrels	37.50	1,915	200,000	Not available
Percentage at WIPP site		2.0	0.019	
Natural Gas				
Quantity, billion cubic feet	490	25,013	855,000	Not available
Percentage at WIPP site		2.0	0.057	
Distillate				
Quantity, million barrels	5.72	293	Not available	
Percentage at WIPP site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	3.66	106	206	11,206
Percentage at WIPP site		3.4	1.8	0.033
Langbeinite[d]				
Quantity, million tons K_2O	0.92[d]	9.3	9.3	Not available
Percentage at WIPP site		10	10	
Crude Oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at WIPP site		0	0	0
Natural Gas				
Quantity, billion cubic feet	44.62	3,865	208,800	2,520,000
Percentage at WIPP site		1.15	0.021	0.0018
Distillate				
Quantity, million barrels	0.12	169.1	35,500	Not available
Percentage at WIPP site		0.07	0.003	

[a]Data Sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.
[b]Data Sources: Hydrocarbons, Keesey (1979) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM 1977).
[c]The U.S. Bureau of Mines (USBM 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.
[d]Estimated from the AIM (1979) study. The USBM estimate for the WIPP site is 4.41 million tons K_2O equivalent, but no comparable USBM estimate is available for the entire district.

SOURCE: U.S. Department of Energy (1980).

production can assure minimal damage to the rock system. Recovery and stimulation methods, e.g., acidizing and hydraulic fracturing, would all be at sufficient depth and under sufficient control to have no effect on the integrity of the repository (Brausch et al. 1982).

Solution mining would not be considered as an extraction method at the WIPP site, but the technique has been suggested as a means of making storage cavities for hydrocarbons. While this mining system requires water to dissolve the salt, the stresses and water convection problems do not differ from those of standard mining when the shape and size of the cavities are taken into consideration. The old Zone IV could possibly be considered for storage sites. Obviously, construction of a storage cavern in any of these zones would not be likely, because any location with 244 m of overburden and a minimum of 9 m thickness of salt will be sufficient to make a suitable storage cavity. Thus, while there is little technical reason for prohibiting storage cavities to be constructed just outside the current site boundary, there is no obvious advantage in doing so. Solution cavities should be prohibited within the site boundary.

POTASH

The Carlsbad region has been the principal source of potash in the United States for many years. The established mines are to the north and west of the WIPP site. The potash zones are also known to be present east of the WIPP site, becoming deeper toward the east. The extent of the potash beds throughout the basin has not been thoroughly investigated, but fragmentary data from oil well logs indicate these beds are not of high grade in potash content or thickness. The potash ore in the vicinity of the WIPP site is in the McNutt Potash Zone, from 412 m to 525 m below the surface and, in general, is insufficient in either grade or thickness to make mining economically attractive at the present time. The mineral langbeinite, $K_2Mg_2(SO_4)_3$, may have some economic value as it has a special application in fertilizer for the types of plants that are sensitive to chloride ions. Within the new site boundary, the reserves of langbeinite are estimated to be about 12 million metric tons, and sylvite is not present.

Questions regarding the classification of these potash deposits as reserves or resources and the timing of future development are complex. The discovery of potash deposits in the Michigan Basin, which are of significant quantity and quality, could affect the value and, therefore, the classification of the Carlsbad deposits (Mathews 1970). The Michigan deposits are some 3,130 m to 3,440 m deep, and their economic recovery has yet to be determined; however, the geographical location with relation to the fertilizer market, water availability, land availability, and other such factors favor their value and might depress the value of the potash deposits in the Carlsbad region.

Although extraction of potash just outside the site boundary may be permitted, it is not currently economic.

The possible effect on potash mining in the former Zone IV of subsidence over the repository excavation in Zone II has been considered by Brausch et al. (1982). Subsidence at the surface or at points below cannot exceed the height of the entry. The distance of the subsidence is related to the extent of extraction and other factors unique to the overlying strata. Thus, with a 3-m-high entry and 25 percent extraction, the maximum subsidence above the cavity would be 0.76 m. Because the salt will flow plastically and the rooms and entries are to be backfilled, this would decrease the subsidence at least by 50 percent, or 0.38 m. In addition, because there are 651 m of overburden, the bulking factor would be sufficient to make this subsidence over the entry even less. These are reasonable assumptions in agreement with mining practice (Society of Mining Engineers 1973). Brausch et al. (1982) use 45 degrees as the angle of draw, noting that this is the value commonly used for salt in New Mexico potash mining operations. Thus, for an excavation at a depth of 651 m, the area that could be disturbed at the surface would extend 651 m beyond the excavation perimeter. If the horizon from which resources are to be mined is 126 m above the repository horizon, the limit of the zone of influence of the repository would be 126 m beyond the excavated edge of the repository.

Potash mining is done by shaft sinking and room and pillar development. If water zones are encountered, they are sealed by grouting. The New Mexico mines are typically free from water intrusion, and the occasional flowing brine seems to come from pockets of limited volume. Several approaches have been made to evaluate the limiting distance of influence from the repository toward the nearest possible mine. It should be pointed out that this distance is between the outermost repository excavations at 651 m and the nearest potash excavation at the potash zone level, i.e., 126 m to 240 m above the repository entry. Using the empirical 45° angle of draw and a difference in depth of 126 m, there is no effect beyond 126 m from the repository, and at a 240-m difference, the limit is 240 m from the repository, and so on.

Brausch et al. (1982) present several more sophisticated analysis methods, with the conclusion that the effects of the WIPP facility would extend a maximum distance of 115 m. They conclude that a potash zone 610 m deep and a repository 655 m deep would show no interaction if separated horizontally by 213 m or more. On the surface above the site the repository could have an influence up to 655 m beyond the outer boundary of Zone II, and the influence of a potash mine at a depth of 610 m in the old Zone IV could extend inward 610 m from the current site boundary. This would leave some 305 m of surface undisturbed, and the distance would be proportionally greater nearer the repository horizon.

Stress-induced increases in hydraulic conductivity were examined (Brausch et al. 1982) for the inert gases and several hydrocarbons. It was concluded that while the mining of potash "would result in a zone immediately surrounding the openings in which the hydraulic conductivity of the rock would be greatly increased," further from the mine the hydraulic conductivity would be less and "therefore no preferential paths for groundwater flow between a potash mine developed within Control Zone IV and the WIPP facility would be expected to be created due to stress induced change in hydraulic conductivity."

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APPENDIX E

BRECCIA PIPES

The possibility of the formation of new vertical pipelike masses of breccia collapse induced by solution working upward into the repository in salt beds from several possible underlying aquifers (Bell Canyon Formation or Castile anhydrite) has been raised (Anderson and Kirkland 1980).

Of the various deep-seated karst landforms and deposits observed in the Delaware Basin, only two have been confirmed by coring to be breccia pipes (Hills A and C), despite the many miles of geophysical surveys (Figure E-1), the drilling of 71 shallow and deep exploration holes in the vicinity of the WIPP site, examination of records of 300 oil and gas wells adjacent to the WIPP site, the detailed mapping of subsurface and surficial deposits, the extensive mining of McNutt potash on three sides of the WIPP site, and excavations and shafts completed as part of SPDV. By 1976, 142 km^2 of potash mines were developed in the region above backreef, reef, and forereef deposits in the Delaware Basin. Despite these extensive excavations, only one breccia pipe was encountered during potash mining, Hill C (Figure E-2). Hills A and C were both cored (WIPP-31 and WIPP-16) and showed breccia present at depth. Two other possible pipes other than Hills A and C were reported (Hills B and Wills-Weaver). One was reported to have been penetrated by one of more than 300 potash exploration holes drilled in the region, and geological and geophysical studies indicate that these most likely are breccia pipes as well. No conclusion can be drawn from the potash drill hole report because data were scanty.

These observations indicate that breccia pipes are exceptions, rather than the rule, in the Delaware Basin, and are far more restricted in their distribution than originally implied by Anderson. Anderson and Kirkland's model (1980) for pipe formation requires the concentrated solution removal of salt at depth (they postulated the Bell Canyon aquifer), presence of unsaturated groundwater at some time in the history of the pipe, an aquifer or aquifers with sufficient hydraulic conductivities and porosities to allow groundwater to transport salt from the aquifer, sufficient gradients to induce groundwater flow, and an outlet or sink for both the water and the dissolved salt. The bounding calculations of Wood et al. (1982) for necessary rates of groundwater circulation and salt dissolution showed that necessary and sufficient conditions for breccia pipe development in the number, size,

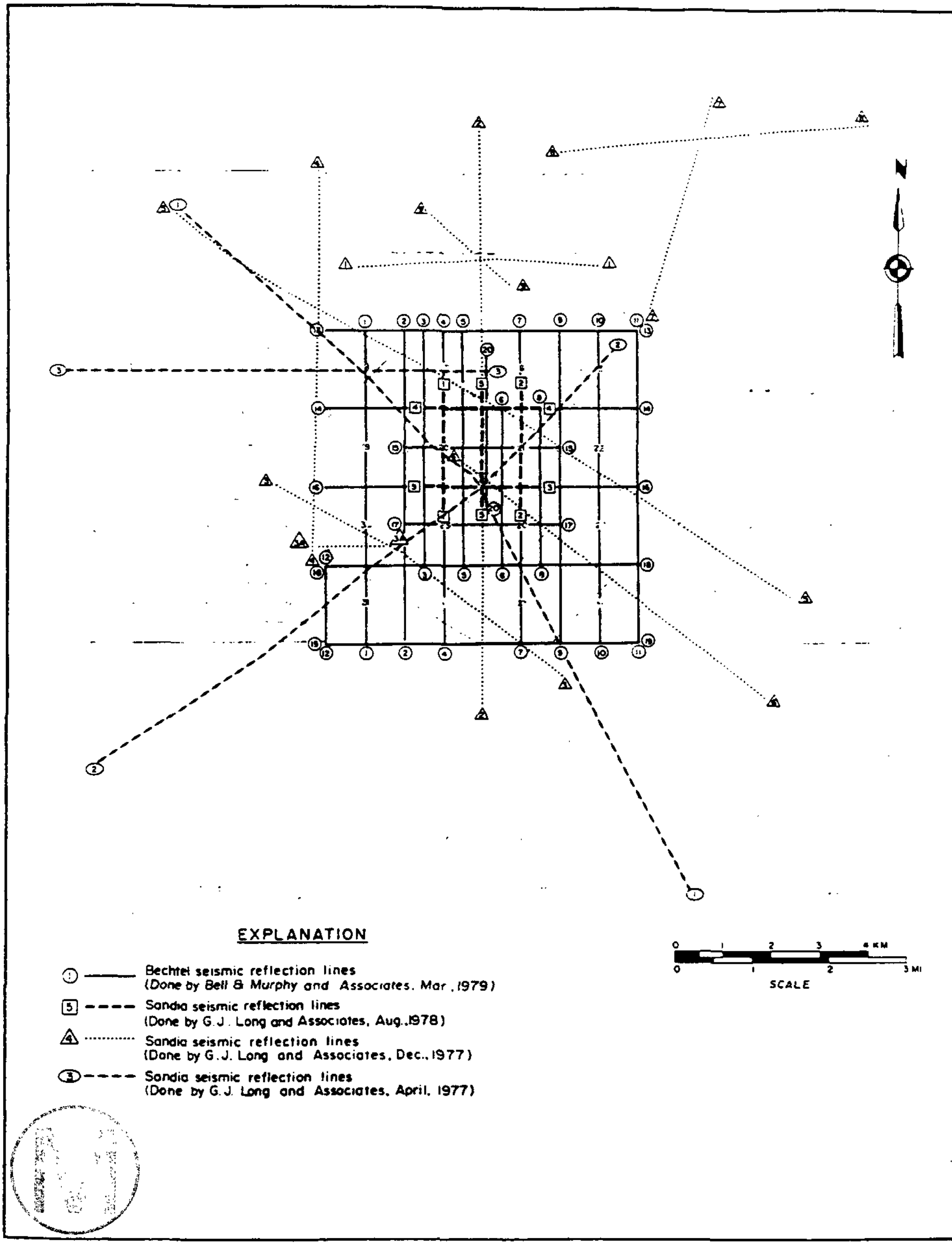

FIGURE E-1 Seismic reflection lines. Source: U.S. Department of Energy (1980-1983).

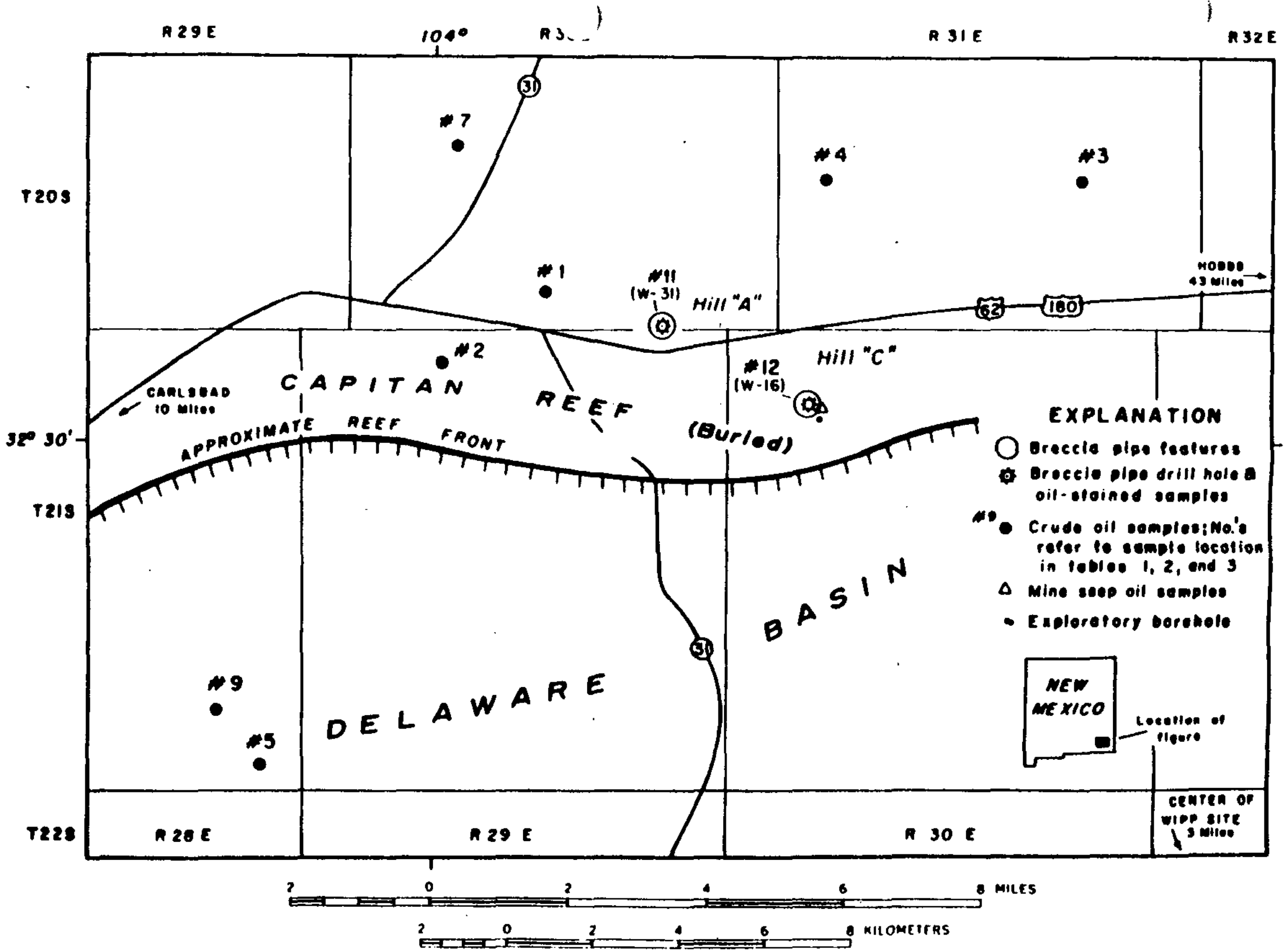

FIGURE E-2 Location of breccia pipe features; breccia pipe, mine seep, and crude oil samples; and approximate Capitan Reef front in Eddy County, New Mexico. W-16 and W-31 are drill holes at breccia pipe features. Source: Palacas et al. (1982).

and time frame required to threaten the integrity of a WIPP repository cannot be met within the Bell Canyon aquifer. This is in agreement with Lambert's (1983) geochemical and isotopic data. More recent data provided by Davies (1983), however, do draw attention to the possibility of zones of higher permeability being present in the Bell Canyon than inferred by Wood et al. (1982) and Lambert (1983). Williamson (1979), for example, proposed a mechanism for the development of deep-sea channels trending toward the basin that may contain thicker, more permeable sands than recognized by Lambert (1983), Wood et al. (1982), and others.

Most workers now agree that conditions could be met for breccia pipe formation only within the Capitan Reef of the Delaware Basin and near its forereef and backreef environment. An abrupt collapse of Salado and Rustler roof rock into a large void temporarily supported by an anhydrite "beam" within salt (Snyder and Gard 1982) or related resistant layer within salt could account for breccia pipe characteristics observed as well as the large diameter and large volume of rock instantaneously displaced into Kermit sink (Baumgardner et al. 1981), San Simon sink, and possibly other related karst features observed near or above the Capitan Reef in the Delaware Basin.

Hill C (Dome C in Vine 1960) and Hill A have been shown to be deep-seated "breccia pipes." R. P. Snyder (U.S. Geological Survey, personal communication to the WIPP panel, 1982) points out that these structures are not unlike a rubble chimney caused by the detonation of a buried nuclear device. Because of their size and potentially disruptive nature, breccia pipes require better understanding, because they are a mechanism that could affect a repository.

Drill-stem tests in borehole AEC-7 indicate that: (a) the 8 m to 10 m thick Lamar Shale Member that occurs near the upper portion of the Bell Canyon is practically impermeable, and (b) the hydraulic conductivity of the brine-producing zone of the Ramsey sandstone in borehole AEC-7 is about 1.2 m/yr (Lynes, Inc. 1979). Hiss (1975) constructed a potentiometric surface map for the Delaware Mountain Group, using a large number of control points. His potentiometric surface map and chloride concentration gradients show that flow is generally to the northeast within the northern part of the Delaware Basin. The average hydraulic gradient, using potentiometric data corrected for fluid density, is about 0.0025 m/m (Wood et al. 1982) and the computed flow in the Bell Canyon is about 0.135 m^3/yr per meter width of aquifer. Allowing for probable ranges in hydraulic conductivity, effective aquifer thickness and hydraulic gradient, probable flow rates were estimated to range from 0.02 to 0.40 m^3/yr per meter of width.

Groundwater quality analyses of samples taken from the Bell Canyon Formation reveal that chloride concentrations range from 1,000 to 190,000 ppm, and that total dissolved solids typically exceed 20,000 ppm for much of Bell Canyon groundwater (Hiss 1975). Hiss's contours of equal chloride concentration (isochlors) roughly parallel the potentiometric surface for the Bell Canyon and increases from southwest to northeast near the WIPP site. Wood et al. (1982) and Lambert (1983) have indicated that the specific source of chloride is difficult to determine, although some of it may be derived from the overlying Castile Formation, having been derived from a more regional, rather than concentrated site originating from a few distinct points, and from reactions within the Bell Canyon aquifer. Wood et al. (1982) computed the water particle velocity to be approximately 0.03 m per year within the Bell Canyon near the WIPP site based on an average hydraulic conductivity of 1.8 m/yr, a porosity of 0.16 and hydraulic gradient of 0.0025 m/m. This travel time in the Bell Canyon from underneath the center of the WIPP site to the nearest known point on the Capitan Reef is approximately 500,000 years. A mechanism is lacking, however, for getting radioactive material from the repository into the Delaware Mountain Group (DMG). At present, heads in the DMG stand above the proposed repository level.

Wood et al. (1982) analyzed two major mechanisms for deep-seated dissolution of salt from halite horizons through the agency of an underlying aquifer at the WIPP site:

- o molecular diffusion along grain boundaries and through fractures in the intervening anhydrite layer; and
- o solute-driven convection, either through a single wide fracture or through a permeable porous zone or fracture network between halite and aquifer horizons.

The latter is a worst-case example similar to that postulated by Anderson.

To demonstrate the dissolution capabilities of the salt removal mechanisms, one-dimensional analytical equations describing the mechanisms of salt dissolution and their interrelationship have been applied to the Delaware Basin. Two-dimensional numerical modeling of flow and mass transport has provided a more precise study of salt dissolution in the Castile Formation and mass transfer to the Bell Canyon aquifer. The results of modeling by Wood et al. (1982) are consistent with observed chloride concentration levels associated with dissolved halite in this aquifer (Lambert 1983). Conditions required to support dissolution within the Bell Canyon include a concentration gradient to drive the diffusion process and a density gradient to initiate convection. Additionally, convection is dependent on the fracture size or porous zone (fracture network) permeability. As shown in the Wood et al. (1982) analysis, convection can be substantially greater than diffusion for a fracture greater than 0.0015 m, or for intrinsic permeabilities greater than 10^{-16} m^2. However, for conditions in the Delaware Basin, the Bell Canyon Formation will limit the dissolution mechanism because the concentration and density gradient will be controlled by the aquifer transport rate. The quantity of water currently moving through the Bell Canyon aquifer is inadequate to transport the necessary amounts of salt implied by Anderson's original brine-density model.

Two implausible worst-case scenarios were also developed by Wood et al. (1982), and the sizes of associated solution cavities estimated. Based on the calculated solution cavities, the possible implications of development of a dissolution cavity at the Halite I horizon on the integrity of the underground WIPP facility were assessed.

The following conclusions were reached:

- Observed site features that provide evidence for deep-seated dissolutioning are at the Capitan Reef margin and consist primarily of breccia pipes. The origin of other dissolution features observed in the basin is open to interpretation, although near-surface rather than deep-seated dissolutioning appears more plausible. One exception may be the FC-92 structural depression 2 km north of WIPP, discussed by Davies (1983).
- The residence time of groundwater in the Bell Canyon aquifer is relatively long, with a flow rate that requires more than 2 million years to travel from recharge near the west reef margin to discharge at the east section of the Capitan Reef.
- The potential dissolution mechanisms include diffusion and convection from halite zones to the aquifers. Computation of the present dissolution rate, based on observed chloride concentration levels in the Bell Canyon, indicates that diffusion and possibly very weak convection result in the removal of halite from the Castile Formation. However, convection may be considerably more significant at locations adjacent to the Capitan Reef aquifer.
- Evaluation of the present DMG hydrogeologic and geochemical conditions and review of their potential range of values indicate that halite dissolution associated with the Bell Canyon aquifer will not impact the underground WIPP facility. A solution zone of less than 0.1 m in height was calculated, based on the maximum dissolution rate in 10,000 years.
- Based on an analysis of potential changes in the hydrologic characteristics (i.e. hydraulic gradient) of the Bell Canyon aquifer, a possible increase in flow rate of one order of magnitude in the future would not impact the WIPP facility over the period of investigation, 10,000 years.
- Based on an analysis of the maximum potential dissolution rate associated with convective and diffusive dissolution mechanisms at the Bell Canyon aquifer-Castile Formation interface (i.e., worst case), no impact should be observed at the underground WIPP facility during the period of investigation, 10,000 years.

The analysis by Wood et al. (1982) of deep-seated dissolution due to diffusion and convection (brine density flow)(Anderson and Kirkland 1980), and the significance of the parameters that influence these dissolution mechanisms are revealing. Brine density flow or convective dissolution as a potential mechanism for removal of halite is possible in areas overlying and immediately adjacent to the Capitan Reef aquifer where high groundwater flow can occur and water is undersaturated with respect to NaCl. However, geochemical data suggest that convective dissolution by water from the Bell Canyon aquifer is not very significant and results in dissolution at the rate no greater than that associated with the diffusive dissolution mechanism. Furthermore, the very low flow of the Bell Canyon aquifer and the associated salt transport rate indicate that significant convective dissolution of halite in the overlying Castile Formation would be precluded due to the inability of the aquifer to maintain the density gradient for any significant period of time (Wood et al. 1982). The potential significance of channel sandstones with hydraulic conductivities ranging from $\sim 10^{-7}$ to 10^{-4} cm/sec as described by Davies (1983) was not considered by Wood et al. (1982).

The deep dissolution analysis by Wood et al. (1982) has adequately set bounds on the rates and unimportance of sub-Castile dissolution process to breccia pipe formation. The question of more regional subsidence deformation discussed by Davies (1983) warrants further study, even though such subsidence is unlikely to be as disruptive to a repository when compared to pipe formation. Davies points out that the rate of subsidence will have an important bearing on the mechanical behavior of salt. For ductile subsidence, a repository constructed in the middle of the salt unit would maintain its hydrologic integrity through a large portion of the subsidence. Intermediate time rates of subsidence might have a different result.

Several questions remain unanswered: Where are conditions favorable for possible future breccia pipe formation? Are San Simon Sink and Kermit Sink modern examples of breccia pipes in various stages of formation? Are there possible circumstances available for renewed breccia pipe formation at or near the WIPP site? How might specific high-risk sites for future pipe development be identified?

It is important to be sure that the reef facies margin immediately northwest, north, and northeast of the WIPP site is accurately known, and that there are no smaller fringing reefs present between the site and the main reef that may be hydraulically connected with it. Reef masses tend to be rather complex when traced in their development through time and space. However, no such fringing reef occurrences were noted in test holes, and a number of industry deep well logs, borehole geophysical data, and seismic refraction data were used in test holes AEC-7 and AEC-8 to show that the southern edge of the reef is at least 11 km away from the northern edge of the WIPP site.

Judging from the importance that zones of fracture concentration have on the location of Carlsbad and other caves in the Guadalupe Mountains (Parizek 1979), similar structures also most likely contributed to the formation of caves and conduits within buried reef rock. Fracture trace-related and lineament-related structures that intersect reef rock are major candidate sites for possible present and future sinkhole and breccia pipe development. In any event, the first available reef rock is rather distant from WIPP, and breccia pipe development at a distant site would be of no consequence to WIPP. These structures are more likely to influence rates of water flow and salt dissolution within the Rustler Formation above the repository.

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APPENDIX F

SALT DISSOLUTION, BRINE RESERVOIRS, AND KARST

Containment of radioactive wastes at the WIPP facility hinges on the long-term integrity of the evaporite section, which will be subjected to persistent dissolution, to perturbation during the development of the repository and following its decommissioning, and to possible future human intrusion.

Salt dissolution can progress from the top of the salt section, from below, and within individual salt beds. The rate of dissolution is directly related to the volume of water that comes in contact with salt in a given time period, the chemical quality of this water, and the rate at which dissolved salt can be transported within and from the aquifer. On a geological time scale, the dissolution can be rapid. Few outcrops of soluble salt beds are ever observed in humid regions or even in moderately arid regions because the shallow, unprotected salt has long since been leached away. However, salt that is deeply buried, or covered by poorly permeable strata that restrict groundwater circulation, can survive for long periods of geological time even in basins with active groundwater circulation. Permian salts of the Delaware Basin of New Mexico and west Texas are good examples, for they have persisted for more than 200 million years despite active dissolution within some regions of the basin.

Reliable estimates of the total amount of Salado and Castile evaporites removed by dissolution, especially in relatively recent times, are difficult to make because of (a) original heterogeneities of deposition, (b) ambiguous identification of members or marker beds, (c) partial removal of halite by dissolution or early subaerial erosion, and (d) perturbation of original bedding thicknesses by localized deformation (Lambert 1983).

Episodes of uplift accompanied by erosion and dissolution of evaporite beds are described by Powers et al. (1978):

> Periods of terrestrial deposition alternated with erosional episodes, so that a series of non-marine deposits separated by angular unconformities blanket the evaporite beds at the site. These angular unconformities represent intervals during which salt beds at the WIPP site were tilted and subjected to potential dissolution. At least four erosional episodes separated by

> depositional intervals are recognized: (1) early Triassic time in which the Dewey Lake Redbeds were tilted and eroded to a slight angular unconformity before deposition of the Upper Triassic Dockum Group; (2) Jurassic-Early Cretaceous time in which the Dockum Group was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous); (3) a Late Cretaceous through mid-Tertiary erosional interval when the region was again tilted and the Triassic Dockum Group of sediments was bevelled for a second time; and (4) a post-Ogallala (post-Pliocene) uplift and erosion in early Pleistocene time, prior to which deposition of the (Kansan?) Gatuna formation took place. Subsequent to deposition of the Gatuna, there probably were pluvial intervals corresponding to the Illinoisian and Wisconsin glaciations during which accelerated erosion in these wetter times occurred in the area of the WIPP site.

Each period of tilting, which was accompanied by the potential for renewed erosion, also afforded an opportunity for salt flow by plastic deformation along the imposed gradient and salt deformation as the salt impinged against reef abutments or responded to uneven, differential sediment loading or erosional unloading. Salt deformation of this type may account for the origin and distribution of isolated pressurized-brine reservoirs found in the Castile. To the extent that some "deep dissolution" features are recognized today in salt at depths of several thousand feet below the surface, it seems likely that subsurface dissolution of salt could have started at comparable depths beneath the surface as soon as early-Triassic time. Episodes of active dissolution most likely occurred during the Jurassic and late-Cretaceous to mid-Tertiary erosional intervals, as well as during pluvial periods corresponding to Pleistocene glaciation.

Recent regional rates of salt removal from the top and bottom of the Delaware Basin evaporite have been estimated from a knowledge of salt dissolution mechanisms, regional groundwater flow systems, and the geochemistry of its groundwaters (Powers et al. 1978, Wood et al. 1982). Concentrated, more localized deep dissolution processes may give rise to breccia pipes, sinkholes, and other large-scale karst features such as the FC-92 structural depression 2 km north of WIPP (Davies 1983). Some of these karst features formed in part in a localized catastrophic manner rather than by slow regional subsidence. Abrupt collapse of large volumes of consolidated and unconsolidated strata, as occurred at the San Simon and Kermit sinks, is possible only where void space formed at depth by slow differential dissolution of soluble strata. Each of these salt dissolution processes will be reviewed briefly as it pertains to the long-term geological stability of WIPP.

The present rate of salt dissolution has been estimated for the top of the halite within the Rustler and Salado formations (Powers et al. 1978; Bachman 1974, 1980), and more recently for the base of the Castile Formation at the Castile-Delaware Mountain Group contact (Wood et al.

1982). Many lines of convergent evidence were reviewed by Wood et al. (1982) and Lambert (1983) to help bound rates of basal Castile salt dissolution. Local and basinwide stratigraphic and structural observations were considered in these analyses, as well as mineralogical and textural relationships observed in caves and cores. Lambert (1983) presented additional data obtained from chemical and isotopic analyses of rocks and solutions regarding equilibrium relationships of brines and other groundwaters obtained from various sources in the Delaware Basin. These lines of evidence provide support for estimates of dissolution rate that previously were based largely on stratigraphic and geomorphic evidence. Additional evidence regarding dissolution rates is currently being sought from incongruent phase relations (Lambert 1983).

Erosion by solution and fill is a mechanism originally proposed by Lee (1925) for shallow dissolution of gypsum terrain, characterized by incision of dendritic drainage patterns and development of underground drainage channels that collapse as soluble materials are dissolved. Bachman (1980) concluded that this mechanism is active in sections of the Delaware Basin underlain by gypsum, resulting in a chaotic jumble of less soluble rock as an end product.

Bachman (1980), Christiansen (1971), Jagnow (1979), and others have described a shallow process of phreatic dissolution of soluble rocks within open conduits that contain freely circulating groundwater that is undersaturated with respect to the rocks (such as carbonate rocks, anhydrite, gypsum, and halite) being dissolved. This process is differential in nature and can produce large open cavities, such as Carlsbad and related caverns in the Guadalupe and Delaware mountains and smaller cavities noted in Nash Draw. Many of these caverns in the Capitan limestone exhibit structural control, i.e., zones of fracture concentration, which are also likely to influence present development of solution permeability within Capitan Reef rock where buried by Salado, Rustler, and other strata. Similar zones of fracture concentration are present in the back reef sediments of the Artesia Group that lies shelfward of the Capitan Reef and appear to have helped localize numerous sink holes and collapse structures.

A different origin for some karst deposits and landforms was proposed by Anderson (1978, 1982a). He has suggested that many of these features were created by deep-seated solution activity, which he considered to be an ongoing process within the Delaware Basin. It was his view that the region of concentrated salt dissolution activity has migrated from west to east through geologic time, as well as along and away from the margins of the Capitan Reef. In support of his hypothesis of deep-seated dissolution, Anderson cited the presence of many sinks, domes, and breccia pipes in various parts of the Delaware Basin, and the thinning of halite layers I, II, and III deposits in the Castile Formation near the western margin of the basin.

As a corollary of the deep-seated dissolution hypothesis, Anderson and Kirkland (1980) proposed a brine-density flow model to account for breccia pipes in the Delaware Basin. For this mechanism to operate, fractures must expose the base of the evaporite section to undersaturated solutions that begin to dissolve salt. As salt dissolves, water becomes more dense and sinks into the lower part of the aquifer, allowing new unsaturated waters to come in contact with the salt in a self-perpetuating manner. Overlying strata collapse into the cavity created by the dissolution. Anderson and Kirkland suggested the Bell Canyon Formation as the aquifer providing the undersaturated solution. It immediately underlies the salt sequence.

Recent work, however, has cast doubt on the ability of the Bell Canyon Formation to supply the necessary flow of undersaturated fluid (Lambert 1983, Wood et al. 1982). Five lines of evidence were presented by Lambert (1983) to show that the Bell Canyon is an unimportant aquifer:

- o extremely limited quantities of water produced from but a few thin Bell Canyon Formation horizons;
- o Bell Canyon water is highly saline, but not completely saturated with sodium chloride under the evaporites (Hiss 1975);
- o the salinity does not rise abruptly from west to east as evaporites appear in the overlying section (Hiss 1975);
- o the water contains solutes in combinations not found in the evaporites (Lambert 1978); and
- o there is little evidence for appreciable movement of water in the Bell Canyon (Mercer and Orr 1979).

Anderson (1982a) has agreed that the Bell Canyon is an unlikely source of solutions for the brine-density mechanism but has suggested instead that deep dissolution is concentrated in layers of fractured anhydrite near the Salado-Castile contact. The alleged flow in this layer, called "blanket" or "strata-bound" dissolution, involves the lateral movement of water along a permeable bed, adjacent to which soluble rock dissolves. More rock dissolves as new void space is created. Such dissolution in this and other anhydrite beds, according to Anderson (1981b), has removed nearly 50 percent of the halite in the Delaware Basin by a process that he believed to be still active and still proceeding eastward at significant rates. More recently, Anderson (1981b, 1982a) has tied this process to the origin of brine reservoirs in Castile anhydrites as well. He has dropped the Bell Canyon as an important conduit for significant salt removal and breccia pipe formation as proposed in his earlier papers. Davies (1983) indicated that the Bell Canyon may still be capable of producing more widespread salt removal and that new bounding calculations are justified.

Bachman (1980) and Lambert (1983) have agreed that strata-bound dissolution occurs, but have stated that it operates only near points of recharge where waters are more likely to be undersaturated with salts and where groundwater sinks are available for salt and water removal. They did not agree with Anderson that this mechanism is widespread or is responsible for pressurized-brine reservoir formation. To date, no evidence has been provided to show that anhydrite beds within the Castile or Salado formations serve as regionally interconnected aquifers in the basin.

Hydraulic heads in the Bell Canyon aquifer stand above the proposed repository level, and only human intrusion could introduce radionuclides into the Bell Canyon. Extraction of oil and mostly gas in the northern section of the Delaware Basin has not caused a drawdown in potentiometric heads within sub-Bell Canyon reservoirs that have reversed hydraulic gradients in the Bell Canyon. Also, estimated flow rates in the Bell Canyon show that nearly 500,000 years may be required for its waters to move from beneath the WIPP site to the nearby Capitan limestone aquifer, assuming that it is hydraulically interconnected to the Bell Canyon aquifer.

The Capitan limestone is an important aquifer, with extensive solution porosity where exposed west of the WIPP site as well as where buried in the northern and eastern margin of the Delaware Basin. Hiss (1975) reported high porosity zones within buried reef rock as shown by five occurrences of bit drops during drilling of 3.6 to 18 m. Hiss's model for regional groundwater flow within the Capitan limestone and adjacent strata has been modified by Lambert (1983) to be consistent with current isotopic data. Lambert concluded that

o virtually no involvement of the Bell Canyon exists in either groundwater recharge or discharge from the Capitan;

o the reef shelf system may be divided into various units that can act as either recharge or discharge areas for the Capitan; and

o the Bell Canyon Formation is not being actively and continuously recharged by any known meteoric or groundwater source in the Delaware Basin as revealed by isotopic data (Lambert 1978).

All current lines of evidence have led Lambert (1983) to conclude that water movement in the Bell Canyon, Castile, and Salado formations in the north central Delaware Basin is either imperceptibly slow or nonexistent and that strata-bound dissolution in unspecified beds, most likely anhydrite layers, is the most plausible model for efficient removal of evaporites at depth. What to do with the saturated brine of dissolution origin remains a major problem with the strata-bound model. This is the same issue on which Anderson's thesis is vulnerable. A plausible water and solute sink needs to be located for salt to be removed.

Dissolution processes described by the Lambert model are not likely to disrupt surface support facilities during operation of the facility, but in time could further increase the permeability of the Magenta and Culebra dolomite members within the Rustler Formation as salt is slowly dissolved from the Rustler and the top of the Salado. In the long term, this could influence the permeability of the Rustler Formation near the upper portions of shafts and borehole seals following backfilling of the repository. Permeability increases within any of the Rustler units will (1) increase groundwater flow rates, (2) accelerate rates of salt dissolution by a feedback loop mechanism, and (3) reduce the thickness of the protective salt layer above the proposed repository. None of these changes, however, is likely to be significant to waste isolation under present climatic conditions or before TRU waste decays to acceptable levels if no mechanisms are provided for releasing radionuclides into the Rustler aquifer.

The formation of a breccia pipe under a repository according to Anderson and Kirkland's (1980) model might have caused serious disruption. The work of Wood et al. (1982), however, greatly restricts the location in the Delaware Basin where breccia pipe formation might be possible, i.e., above the permeable Capitan limestone. The distribution of the Capitan limestone and its southern limits are well known. The northern outer edge of Zone IV is at least 11 km south of the mapped southern extension of the reef; hence, there is no chance for a future Capitan Reef-related breccia pipe to disrupt the repository.

Anderson (1982a) concluded that fractured anhydrite beds observed within the Castile Formation are regionally interconnected, and that they serve as aquifers containing actively circulating water that may be quite young and is capable of dissolving significant amounts of salt. Lambert's (1983) strata-bound hypothesis is testable, but not enough data have yet been compiled to support a final conclusion. However, the many cores taken from Castile anhydrite beds do not show open fractures and brine except where brine reservoirs have been encountered along anticlinal structures near the Capitan Reef. This suggests that brine reservoirs are genetically related to folding of evaporite beds and derive their built-in and confined pressures that exceed hydrostatic pressure from sources other than existing groundwater recharge areas. The very numerous oil and gas industry wells in the basin do not show brine saturation within the Castile anhydrite beds nor did they penetrate brine reservoirs. These observations are hard to reconcile with Anderson's hypothesis, but do not completely prove it wrong.

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NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF APRIL 1987
PLANNED SORBING-TRACER FIELD TESTS

NATIONAL RESEARCH COUNCIL

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

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Mr. John Mathur
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Mr. Mathur:

The Waste Isolation Pilot Plant (WIPP) panel of the Board on Radioactive Waste Management (BRWM) has considered in detail the sorbing-tracer field test planned at the WIPP site, and herewith presents comments on some aspects of the plan.

The test is required as an item in the Working Agreement for Consultation and Cooperation between DOE and the State of New Mexico. In requesting the test, the State (through its Environmental Evaluation Group) pointed out the uncertainties in the use of laboratory-determined K_d (distribution coefficient) values for predicting retardation of radionuclide movement in flowing ground-water, and the consequent need to have in-situ K_d data for scenario analyses.

The scenarios for which the data are needed involve the effects of migration of ground-water containing dissolved radionuclides from the WIPP repository into the Culebra member of the Rustler Formation (about 400 meters above the repository), and then through the Culebra into the accessible environment. The movement of the groundwater could be caused by: (1) collapse of salt following repository closure, forcing any liquid contained in the repository up the shaft; or (2) injection of overpressured brines from somewhere beneath the repository; or (3) drilling of wells into the buried waste at some future time when existence of the repository has been forgotten. Although unlikely, these are often-cited scenarios. If a radionuclide solution does find its way into the Culebra member, this rock unit (consisting chiefly of fractured dolomite) is known to be an aquifer that could permit long-distance movement. The rate of travel of the radionuclides would be determined in part by how effectively they are sorbed on the dolomite, and it is this sorption that the test is designed to measure.

The original plans for the test, as described to the panel at its meeting in February 1986, involved the injection of several tracers into the Culebra dolomite in one well and their detection in adjacent wells after various time intervals. Prior injection of nonsorbing tracers would give a measure of the rate of ground-water flow, and the ratio of rates of movement of sorbing and nonsorbing tracers would indicate the amount of retardation. Retardation factors so determined could then be used in performance-assessment models designed to test compliance with EPA standards for escape of radionuclides into the accessible environment. The factors also would be useful, it was hoped, for comparison with retardation factors calculated from laboratory K_d measurements, a comparison intended to provide information on the reliability of laboratory data as a basis for predicting retardation in natural environments. At the time of the February meeting no decisions had been made as to the specific substances to be used as sorbing and nonsorbing tracers; because it was assumed that use of radioactive substances would not be permitted, a variety of possible analog elements was under consideration.

A more detailed and somewhat revised plan for the test was presented to the panel at its meeting in September 1986, in the form of a memorandum from Al Lappin (of the Sandia National Laboratories) to Dick Crawley (DOE/WPO) and Mary Wilson (DOE/ALO), dated 23 September. The memorandum noted that fielding of the test had been delayed by budgetary constraints; that a probable starting date was still uncertain; but that the target date for completion of the final performance assessment for the repository (end of fiscal year 1992) would require that the test be started within the next two or three years. The memorandum records progress in field and laboratory work related to the test, and is optimistic about the possibility of obtaining permission to use radioactive tracers rather than analog elements. It is recommended in the memorandum that starting the test be delayed until a good deal of additional field and laboratory investigation has been completed to provide an adequate hydrologic and geochemical background. The following are included among the recommended research projects: field studies of matrix and fracture flow in order "to determine relevant transport mechanisms within the Culebra"; experiments "investigating matrix diffusion within the Culebra Dolomite"; autoradiography for sorption of transuranic elements; study of cation exchange on the clays of the Culebra; investigation of possible coprecipitation of radionuclides with carbonates and sulfates; and oxidation/reduction experiments to study potential effects of pyrite and organic matter as sorbers of some radionuclides.

The panel was skeptical of the usefulness of the test as described in the original plans. Grounds for skepticism were: (1) doubt that results would be significant, in view of the then-incomplete knowledge of Culebra hydrology; (2) doubt that results could be generalized to the Culebra as a whole, from data obtained at a single hydropad, in view of the known variability in Culebra geochemistry and fracture geometry; (3) insufficient allowance for changes in ground-water chemistry due to drilling fluids, fluids added for nonsorbing-tracer tests, and exposure to air; and (4) poor choice of elements planned for use as analogs. Some panel members were so dubious about the possibility of getting meaningful results, and so impressed with the probable waste of time and money, that they favored abandoning the test altogether; others, although recognizing the strong chance of failure, thought that the test was important enough to be worth trying, with some suggested modifications.

The revised plans for the test, as described in the Lappin memorandum, have impressed the panel more favorably. There is still a difference of opinion about the probability of obtaining useful results, but in view of the need to fulfill a commitment to the State of New Mexico and in view of the often expressed desirability of obtaining in-situ K_d values (for example, Letter Report on the Proceedings of the NRC/ORNL Workshop of 13-15 May 1986, page 6), the panel agrees that the test should be carried out.

The panel strongly urges that the timing and conduct of the test be based on the Lappin memorandum rather than the proposal of February 1986. The panel emphasizes the following specific recommendations, some of them similar to those in the memorandum and others somewhat modified:

(1) The test should be preceded by a calculation of the probable rate of release to the accessible environment of the important radionuclides in TRU waste on the assumption of no retardation due to sorption, i.e., that $K_d = 0$. The calculation will give a rough idea of the amount of retardation that must be assigned to sorption if the release is to meet EPA requirements. If the calculation shows that the release is within EPA limits without help from sorption, the sorbing-tracer test would seemingly be superfluous. But the uncertainty in such calculations is necessarily large, and the test should proceed regardless of the numbers that the calculation produces.

(2) The drillholes selected for injection and recovery should be ones for which the history since drilling is well known, particularly with respect to the composition of the drilling fluid and any other fluid that has been subsequently added. These fluids must be flushed before the experiment is started. Preferably, the selected holes should be ones that were drilled with air only.

(3) Of the additional research recommended in the Lappin memorandum, the items regarded by the panel as most important are further field study of Culebra hydrology in different parts of the WIPP site and autoradiographic study of Culebra specimens to determine what phases are active sorbents for transuranic elements. The panel thinks that these two items should be completed before the test is started, but suggests that preparations for the test be made while the research is in progress.

Other recommended research items, in the panel's opinion, need not be completed so expeditiously, since they could lead to long delays in getting the test underway. It would be desirable, certainly, to know more about details of matrix diffusion, about cation exchange on clay minerals in the dolomite, about coprecipitation of radionuclides, and about possible effects of pyrite and organic matter, but these could easily become long-term research projects and are not directly relevant to the empirical determination of retardation factors for performance assessment purposes.

(4) The panel strongly urges the use of radionuclides rather than analog elements as sorbing tracers. A possible exception might be made for strontium, since the chemical behavior of the nonradioactive form is identical to that of ^{90}Sr; another possible exception would be lanthanum as an analog for the chemically very similar americium. But the plutonium and neptunium have no close analogs, and use of radioactive isotopes is essential. Objection can be raised on the grounds that these isotopes would contaminate the subsurface [illegible] give ambiguous results. This difficulty can probably be surmounted by the use of isotopes or isotope ratios different from those in the waste, so that contamination from the test would be recognizable. The panel further recommends that the test be limited to a few tracers, perhaps only Sr, Pu, and Am, rather than the large number listed in the original proposal. For the non-sorbing tracer the Panel recommends the use of both ^{3}H or ^{81}Kr.

(5) In the absence of sufficient information about the variability of the formation, it is not possible to determine the number of hydropads needed to obtain a statistically significant result. The test should be performed at more than one hydropad, preferably at at least three, to give some sense of the possible variability. The geochemistry and characteristics of graoundwater flow vary greatly from place to place in the Culebra aquifer, and results of the test at a single hydropad would not be representative of the aquifer as a whole. Even with three hydropads the results will not be truly representative, but three will be better than one.

(6) Preferably the field test should be accompanied by laboratory determinations of K_d using chunks of dolomite from drillcores with their bentonitic drilling mud. This recommendation is less important than the others, but such measurements would be a useful contribution to the on-going argument as to whether laboratory measurements of K_d can be depended on as a guide to the extent of sorption in natural environments.

Sincerely,

[signature]

Konrad B. Krauskopf
Chairman, WIPP Panel

KBK:PBM:jc

NATIONAL ACADEMY OF SCIENCES

REPORT OF MARCH 3, 1988
BRINE ACCUMULATION IN THE WIPP FACILITY

MAR - 4 1988

NATIONAL RESEARCH COUNCIL

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

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BOARD ON
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March 3, 1988

MEMORANDUM

TO: Attendees of the February 18-19, 1988 WIPP Panel Meeting

FROM: Peter B. Myers PM/jk

SUBJECT: Report on Brine Accumulation in the WIPP Facility

The enclosed report was presented to, and discussed with, the New Mexico Congressional Delegation on March 3, 1988 at 2:30 p.m.

Participants in the Augmented WIPP Panel Meeting
of 18-19 February 1988

Konrad B. Krauskopf, Chairman, Stanford University (geology, geochemistry)
Samuel Basham, Battelle Memorial Institute (engineering, civilian waste program)
John O. Blomeke, Oak Ridge National Laboratory (chemical engineering)
John D. Bredehoeft, U.S. Geological Survey (hydrology)
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E. William Colglazier, University of Tennessee (engineering risk analysis)
Fred M. Ernsberger, University of Florida (materials science)
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George M. Hornberger, University of Virginia (hydrology, environmental sciences)
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Report on Brine Accumulation in the WIPP Facility

Background

The Waste Isolation Pilot Plant (WIPP) facility, a proposed repository for transuranic radioactive waste, is being constructed in a thick bed of salt 650 m (2150 ft) under the surface in southeastern New Mexico. When the repository has been filled with waste and sealed, the salt is expected to move by plastic flow into repository openings and ultimately to lock the waste in a solid mass of crystalline salt. In this manner the waste would have minimal contact with moving groundwater, because no appreciable continuous flow of water is possible through the nearly impermeable structure of an undisturbed salt bed. It has been known for a long time, however, that the salt does contain some water (averaging about 0.5 percent), in the form of brine both within and between the salt crystals. The presence of water at WIPP is shown by efflorescences that appear on walls of rooms and tunnels, by salt icicles that form where brine drips from the ceiling, and by the brine that collects in some of the holes drilled into the floor. The amount of brine is small, so that the workings are kept dry by normal ventilation procedures and will remain dry as long as the repository is open. When the repository has been sealed after filling with waste, however, brine is expected to accumulate slowly in repository openings. The amount of this accumulation is uncertain, and different estimates of the amount have recently aroused controversy.

Scientists at the Sandia National Laboratories (SNL), the technical consulting agency for DOE, maintain that the amount of brine accumulation is small, and calculations indicate that it will be absorbed by the backfill material to be placed in the rooms and tunnels. Thus no interference is expected on the basis of preliminary observations with the plastic flow of salt into disposal rooms and around the waste packages. A contrary view* has been expressed recently by a local group of scientists, most of them from the University of New Mexico (the Scientists Review Panel: SRP), who suggest that the amount of accumulation may be large enough to entrain both backfill and waste in a mobile radioactive "slurry." Such a fluid would prevent consolidation of the salt and might move to the surface to release radioactive material in quantities exceeding EPA standards. Because of this concern, SRP recommends a hold on repository construction and on DOE's plan to start bringing large numbers of waste drums to the site in October 1988 for a projected five-year pilot phase of the repository operation. Scientists in the State of New Mexico's Environmental Evaluation Group (EEG), while not advocating a halt on repository excavation or on experimental work with radioactive waste in the repository tunnels, also feel that uncertainty regarding the quantity of brine is sufficient to warrant serious study before large numbers of waste drums are placed underground.

The National Academy of Sciences, through its Board on Radioactive Waste Management and its WIPP Panel, has been asked to express an opinion as to how well existing data resolve these conflicting viewpoints. In response to this request, the Panel has reviewed pertinent documents and convened a special meeting in Albuquerque (18-19 February 1988) at which scientists from SRP, SNL, and EEG presented their views. The Panel was assisted in its review by several members of the Board and three invited consultants. This report is a record of the augmented Panel's conclusions.

Statement of the Problem

The essential issue is one of balance between several rates, principally: (1) the rate at which brine seeps into repository openings from the salt; (2) the rate at which the openings are closed by plastic flow of the salt; and (3) the rate at which gases are generated in the drums and dissipated. If the first rate is slow enough, the plastic creep can be expected ultimately to immobilize the waste in solid salt; this is the goal of SNL's repository design. If brine inflow and gas generation are too fast, complete consolidation of the salt would be prevented, and mobile fluids (liquid plus gas and entrained solids) would collect in the remaining open spaces of the waste-filled rooms; this is the result feared by SRP and recommended for further study by EEG. The issue of balance has been recognized for a long time, but because all three rates are known only over such broad ranges of measured values, complete resolution has not been possible.

(1) The rate of brine inflow depends chiefly on the permeability of the salt and the difference in pressure acting on brine within the salt and in the repository openings. Permeability measurements have been attempted in many ways, all of which give ranges of values—hardly surprising, since salt beds vary in composition and structure from place to place. Measured values lie predominantly in a narrow range of very low permeability (10^{-8} to 10^{-9} darcy), but locally the values are somewhat higher and a very few are several orders of magnitude larger still. Visual observations of tunnel walls (both during previous visits by the Panel to the WIPP site and as shown on numerous photographs displayed by SNL) indicate that areas of higher permeability occur in discrete zones of limited extent. In estimating rates of brine inflow, SNL uses permeability values at the high end of the in-situ measured range. The larger values used by SRP were from drill stem boreholes made by oil exploration companies, and these tests are not considered as reliable as those made for the express purpose of determining permeability at the emplacement horizon.

The initial difference in pressure between the salt and open disposal rooms can be specified in a narrower range, as somewhere between the hydrostatic and lithostatic pressure in salt at a depth of 650 m (2150 ft) [roughly between 70 and 140 bars (1000 and 2000 psi), respectively]. The pressure difference will decrease markedly at the very end of the period of salt consolidation (and brine inflow will be correspondingly smaller), because any fluid that exists in repository voids will be tightly squeezed.

(2) The rate of closure of the WIPP excavations due to salt movement has been monitored over the past several years. Results to date show that measured rates are substantially faster than initial theoretical predictions, and that complete closure can be expected in about 100 years. The rate of closure will decrease in the final stages because of resistance offered by the compacted waste, backfill, and any brine or gas that may be present.

(3) The rate of gas generation is difficult to estimate. The principal gas to be expected is carbon dioxide from decomposition of organic material in the waste, possibly aided by bacterial activity. A little hydrogen may be produced by radiolysis of waste and water, and larger amounts by corrosion of steel in the waste containers. Small quantities of nitrogen will remain from entrapped air. SNL suggests an overall rate of 220 gm (half a pound) of gas per waste drum in 100 years, but this is no more than an educated guess and is not based on quantitative measurements of actual waste drums in a repository environment. SRP considers this figure too low but makes no specific estimate.

In summary, the important variables on which accumulation or non-accumulation of abundant mobile fluid depends can be known only roughly on the basis of available data. SNL calculates a maximum expectable rate of brine inflow of about 43 m^3, or slightly over 1 percent of the initial volume of the empty room, in each disposal room in 100 years, an amount that preliminary experiments show could be readily absorbed by the planned backfill and would not form a mobile fluid. SRP rightly points out that the amount could be much larger if salt permeabilities higher in the measured range of values are used for the calculation.

Critique of the SRP Scenario

The following discussion will consider whether the chance of fluids accumulating in the amounts, character and with the resulting hazard to the environment that are pictured in SRP's scenario is significant. SRP supposes that abundant brine enters voids in the repository from permeable parts of the salt; that the brine moves through the backfill, corrodes the steel containers of the waste, and becomes a thin and mobile "slurry" containing dissolved and particulate material from the waste, backfill, and corroded metal; that radionuclides exist in the liquid partly as dissolved compounds and partly as attachments to suspended particles; that abundant gas is generated and pressure builds up both from the gas and from salt creep; and that the liquid is forced to the surface either through leaks in the shaft seals or through exploratory drill-holes that happen to penetrate the repository sometime in the future when all records of WIPP's existence have been lost. The various parts of this scenario are discussed in the following paragraphs.

Inflow of abundant brine. As noted previously, abundant inflow is possible but only if it comes from exceptionally permeable parts of the salt, or if the effective bulk permeability is much greater than the average of that measured locally in a few boreholes. Permeable zones in the salt will probably be obvious during repository construction, and it seems likely that they can be avoided as the disposal rooms are excavated. As mentioned above, the amount of brine to be expected is more reasonably estimated from the low permeabilities measured by SNL.

Corrosion of steel containers. Both SRP and SNL assume that the steel will corrode not long after the repository is closed. SRP expects the "soft-steel waste containers [to] disintegrate within ... 20 years"* and become part of the "slurry." The products are more likely to be iron in solution and solid chunks of the container metal that have been partly or completely oxidized or sulfidized.

Formation of "slurry." The term "slurry" in the SRP paper appears to connote a free-flowing liquid containing dissolved and particulate material derived from partial disintegration of backfill, waste, and corroded metal. Most of the backfill is more likely to persist as a dense mush of salt crystals and bentonite, the waste would be in pieces and shreds of various solids, and the corroded metal would form in discrete chunks. The remaining void space, as yet undetermined, will contain brine and gas, and if the permeability is as low as current estimates by SNL suggest, the amount of liquid brine will be small.

Entrainment of radionuclides. The radionuclides from the waste are assumed to be partly dissolved in the "slurry" and partly attached to its constituent particles, and in either form to be freely moving. Because the principal radioactive species is plutonium, which is insoluble in neutral reducing solutions and strongly sorbed by both bentonite and iron oxide, the amount in dissolved form should be very small. It can be reasonably assumed that there would be some particles containing plutonium but this would be only a fraction of the total radioactive material present, and the particles would not travel far if the "slurry" were to move through small openings.

Generation of gas. As noted above, some formation of gas is very likely, particularly carbon dioxide from the decomposition of organic materials in the waste. SRP postulates in addition abundant hydrogen sulfide, which seems improbable because even if it does appear, it would react readily with dissolved iron to form solid ferrous sulfide. Accumulation of much gas and build-up of high pressure by salt creep as the repository openings are compressed appear to be unlikely, because the gas would slowly move out through the salt or through leaks in the seals of shafts and tunnels. If the salt is permeable enough for much brine to leak in, it is likely that gas would tend to leak out as the gas pressure rises toward lithostatic.

Movement of "slurry" to the surface. SRP assumes that radionuclides can reach the surface by two possible routes: (1) through leaks in shaft seals up into an aquifer in the overlying Rustler formation, thence to the surface with groundwater flow in the aquifer; and (2) through exploratory drill-holes that accidentally strike the repository in the distant future. Release by either route could be prompted by the development of high pressure from gas generation or salt creep; release through drill-holes is possible also without pressure, by the entrainment of waste in fluids used for drilling. If the existence of sufficient mobile fluid is assumed, any of these alternatives could bring radioactive material to the surface in amounts exceeding releases specified by EPA standards. In support of the first alternative, SRP notes that SNL has not yet demonstrated a completely satisfactory method of shaft sealing. Recent SNL in-situ experiments with various sealing techniques, however, are very promising. Release to a Rustler aquifer requires that leaks in the seals be not only present but large enough for passage of particulate matter in the "slurry, a requirement that puts an additional strain on the credibility of this route. The postulated releases through drill-holes are the more plausible of the two routes.

It is worth noting that the radioactive releases just described, even if they were to occur, would not result in a major catastrophe at or near the site. Escape of contaminated brine through a drill-hole from a pressurized cavity would cause a temporary spurt of radioactive liquid, and entrainment of waste in drilling fluid might lead to longer-lasting flow; but both events would mean only brief surface contact between a few individuals and slightly radioactive liquid. Serious harm would be highly unlikely. Release to a potable aquifer could be more dangerous because the fluid would be disseminated over a wider area and ingestion could lead to possible significant exposure; but water from Rustler aquifers is not now potable and is not likely to become so in the future. Meeting EPA standards is a requirement, although failure to achieve compliance at this particular site and with this particular assumed sequence of events would not pose a major threat to the health and safety of a large community.

Thus SRP has presented a scenario of radioactive release at WIPP that could conceivably happen but that seems highly improbable. Given extraordinary permeabilities of salt with continuity to a source of water near the disposal rooms, backfill that takes the form of very small particles, steel containers that corrode in a nearly neutral reducing brine or disintegrate into tiny grains of iron oxide, and heterogeneous waste that generates abundant gas as it breaks down into particles—given all these preconditions, it would indeed be possible for a mobile fluid to form that could bring radionuclides to the surface in amounts exceeding EPA standards. But the necessary assumption of a sequence of improbable events coupled to the drilling of exploratory holes that strike disposal rooms does not make the result credible. It will probably be forever impossible to devise a repository so perfect that someone cannot think of a way in which it might be breached; but such a breaching event must prove credible through a sound program of experimental investigation. Nevertheless, it is essential to have a well conceived experimental program at WIPP to reduce remaining uncertainties as a basis for a conservative performance assessment.

Conclusions and Recommendations

In response to the request by the New Mexico congressional delegation, the Panel concludes from its study of currently available evidence that the formation of an abundant mobile fluid in a repository at the WIPP site, as postulated by SRP, is very improbable. SRP has nevertheless highlighted some of the uncertainties, long recognized by the Panel, that remain in the existing data, and by so doing has performed a service. To resolve the uncertainties, the Panel makes the following recommendations:

1. The uncertainties are not considered sufficient to warrant a hold on the research activities currently planned at WIPP. A comprehensive, systematic experimental program is needed and should continue, to reduce the uncertainties and to support a conservative performance assessment as required by EPA. Experimental work is particularly important on the permeability of the salt (in particular, the nature, location, extent and continuity of zones of above average permeability) and the generation of gas from the waste. These

quantities are essential for predicting the amount, character, and migration of any fluid that accumulates, and major uncertainties still exist regarding them; the goal of the experimental program should be to reduce the uncertainties with minimal risk.

2. As a first priority, the planned experimental program for a 5-year period must be better defined. Detailed descriptions of the intended experiments have not yet been published, and, without seeing such descriptions, neither the Panel nor any other scientific group has a basis for a meaningful judgment about their ability to reduce current uncertainties.

3. Some of the experiments will require the use of drums containing radioactive waste, and there should be no change in present plans to bring such drums to WIPP beginning in October 1988. Because of continued uncertainty about achieving compliance with EPA standards, the Panel agrees with EEG[#] that no more drums than those to be used in well-described and necessary experiments be placed underground. Only when the experimental work has substantially reduced the uncertainties about brine accumulation to which EEG and SRP have called attention should additional waste containers be emplaced.

4. Experiments should be designed to lessen uncertainties, not to "verify" preconceived ideas about their probable results. Thought should be given to an appropriate course of action if experimental results turn out contrary to expectation.

5. As experimental results are obtained, performance assessment calculations should be continually refined to test the confidence of achieving compliance with EPA standards.

6. Multiphase models (gas + liquid + solid) should be developed to describe the behavior of the possible complex fluids that may form as brine enters the repository and gas is generated from the waste.

7. Effort should commence immediately to investigate the feasibility of possible technical "fixes" if the problem of fluids in the repository is determined by the recommended experiments to be serious. Examples of such "fixes" are:

   a. the use of "getters" to reduce or control the amounts of gas generated from the waste;

   b. the use of inhibitors to suppress bacterial activity;

   c. methods by which brine in the repository might be drained, for example into some sort of sump;

   d. a decision to leave the repository open for a long period, perhaps 100 years, with ventilation and appropriate monitoring, to ensure consolidation of salt around the waste unhindered by brine or gas pressure build-up;

   e. addition of material to the waste drums to increase sorptive capacity and reduce void space; and

f. as an extreme measure, processing the waste into dense, chemically stable forms before emplacement in the repository.

References

*Evaluation of the Waste Isolation Pilot Plant (WIPP) as a water-saturated nuclear waste repository. Scientists Review Panel on WIPP, Albuquerque, New Mexico, January 1988.

#Potential problems resulting from the plans for the first five years of the WIPP project. Environmental Evaluation Group, State of New Mexico, Santa Fe, New Mexico, February 1988.

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF DECEMBER 1988
EXPERIMENTS ON ROOM CLOSURE RATES

NATIONAL RESEARCH COUNCIL

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

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BOARD ON
RADIOACTIVE WASTE MANAGEMENT
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Room 462
2001 Wisconsin Avenue, N W

December 30, 1988

Mr. Critz George
U.S. Department of Energy
Office of Defense Waste
and Transportation Management
DP-124/Forrestal
Washington, DC 20545

Dear Mr. George:

The Waste Isolation Pilot Plant (WIPP) Panel of the Board on Radioactive Waste Management (BRWM) has reviewed the data on room closure rates from laboratory tests and in-situ experiments. What follows is a suggested design for an intermediate-scale experiment to better define the sources of the discrepancy between the predicted and observed salt creep rates, as requested by the Department of Energy.

Summary

Measurements in underground test rooms [of the order of 5.5m (wide) x 5.5m (high) in cross-section] at the WIPP site indicate room closure rates three to six times greater than the rate predicted by numerical computational codes used to model the deformational behavior of the rooms and associated pillars. The codes incorporate mechanical properties for the salt around the rooms identical to the properties derived from deformation behavior observed in laboratory creep tests on small (i.e., of the order of 50mm diameter x 100mm high) core samples taken from the WIPP site.

It is important to establish the reasons for this discrepancy in order to assess better the extent to which such codes can be used to predict quantitatively the field performance of repository excavations in salt.

For this purpose, a limited number (two to five) of in-situ tests are recommended to observe closure rates around horizontal, circular excavations intermediate in scale (i.e., one meter or so in diameter) between the above mentioned field and laboratory tests. Such tests, by providing a "third set" of independent data, will assist in identifying likely and unlikely causes of the observed discrepancies.

Discussion

Evaporite rocks such as the salt formations at the WIPP site exhibit time dependent deformational behavior when subjected to load. The deformation is related in a complex, non-linear way to the applied stress, temperature, time--and possibly to other variables. Lomenick, McClain and Starfield, for example, used an empirical relationship of the form:

$$E_t = E_o + A\sigma^a T^b t^c \qquad (1)$$

where	E_t	is	the strain of the material at any time t
	E_o	is	the instantaneous (or "elastic") strain that develops immediately upon load application--and is recovered immediately upon unloading
	σ	is	the applied stress (some function of the three-dimensional stress rate)
	T	is	the absolute temperature (^oK)
	t	is	time
	A,a,b,c	are	constants

to analyze deformations around underground openings as part of Project Salt Vault studies at Oak Ridge National Laboratories ["a" for example, was found to be approximately 3, i.e., strain (and strain rate, convergence, and convergence rate) was proportional to the cube of the stress]. The empirical power law was found to provide good agreement with observed behavior for periods of the order of weeks to months.

Sandia staff, as part of their research to predict deformation behavior with good accuracy over the period of the repository loading operations, i.e., of the order of 50 years, have attempted to develop an expression for creep behavior that directly incorporates fundamental creep processes that are operative within the internal structure of the salt. The expression is more complicated than equation (1) above, with a greater number of variables, whose magnitude is determined from analysis of the laboratory test data. Incorporation of the expression into the numerical codes allows modeling of the excavations and prediction of the convergence and convergence rates for the excavations.

Finding that the observed rates of room closure are three to six times larger than those predicted from the laboratory results, Sandia explains the difference by:

(1) refining the creep expression (or "constitutive relationship") to incorporate additional fundamental mechanisms; or

(ii) attempting to assess whether strains occurring during the very early times after the theoretically "instantaneous" (but practically finite duration) load applications are properly taken into account in the measured deformations; or

(iii) speculating that the process of coring and removing samples from the in-situ environment and preparing specimens for laboratory testing significantly changes the observed deformational response to load.

Sandia staff have also noted that an empirical reduction of the in-situ modulus of elasticity of the salt mass by an order of magnitude (factor of 12.5) compared to the laboratory measured value will bring laboratory and field results into quite close correspondence for the periods of field observation used. Although no specific justification is given for this reduction, it is well known that a rock mass may contain cracks and fissures too large to be included in a small test specimen. These cracks can reduce the stiffness (or modulus) of the rock mass compared to small specimens--by as much as a factor of one hundred or so at low stress levels, i.e., when cracks are open and compliant.

With the exception perhaps of the modulus reduction approach, the above explanations of the discrepancy suggest a belief that the laboratory test procedures and results, properly interpreted, are capable of explaining the field observations, i.e., that the "errors of interpretation" lie fully with the laboratory tests. While this may be true, it is also certainly plausible that there may be influences in the field scale tests that are absent (or at least different in degree) in the laboratory situation.

The most obvious of these influences are:

1. <u>Scale</u>. The volume of rock undergoing deformation in the field is very much larger than in the laboratory.

Although the strength of some rock types is known to decrease with an increase in the loaded volume (due to the greater possibility of large, weakening flaws in the larger volume), evaporites are often considered to be less subject to size effects than other rock types. Flaws in evaporites tend to heal with time.

2. <u>Geometry</u>. The laboratory tests are conducted on small (initially unloaded) cylindrical specimens; an axial load is applied to the specimen by a testing machine. The field tests involve rectangular openings in an essentially infinite medium, which deform as a result of the redistribution of preexisting (overburden and lateral) loads.

It is known <u>from laboratory tests</u> that the compressive strength of a hydrostatically compressed specimen in the form of a hollow thick-walled cylinder is several times <u>greater</u> than the strength of a standard solid (cylindrical) test specimen. Thus, geometry does influence strength--although apparently not in a way that would explain the observations at WIPP, where salt around the large rectangular holes is apparently <u>weaker</u> (i.e., creeps more rapidly) than salt in the small, solid cylindrical test specimens.

Tests have been conducted to determine the in-situ state of stress at the repository horizon, to see whether orientation of stress might help to explain the discrepancy between field and laboratory data. Results tend to confirm the expected condition that the principal stresses are all approximately equal to the overburden stress (i.e., "lithostatic"). In addition, although there is some variation with direction in the observed rates of closure of the excavations, this variation is of the order of ±25% of the mean of all observed rates, and hence much less than the 300% (or more) difference between field results and the predictions from laboratory results. Nor can the difference be ascribed to computational error: the numerical code SANCHO used to predict the field results has been "benchmarked" (i.e., shown to give results consistent with other numerical codes and with analytical solutions).

It would appear that in the specific situation of the WIPP site, there are a number of possibilities for explaining the observed discrepancy, in addition to the general scale and geometry effects, and those noted in (i), (ii), and (iii), above. For example:

1. The three-dimensional stress distributions imposed by the size and cylindrical geometry of the laboratory specimens and the testing machine (relatively rigid steel loading) may effectively inhibit deformation compared to the field loading situation, where the loads are applied naturally, i.e., without a mechanical interface.

2. Structural features within the "significantly affected region" around the excavation may contribute to the development of deformation mechanisms that are (a) not possible in the smaller, "effectively more confined" specimens, and (b) not incorporated in the numerical models. Buckling of "slender beams" resulting from sedimentary interfaces close to the wide excavations (i.e., Marker Bed 39 and roof shearing in other areas), and perhaps incipient buckling associated with cracks and fissures in the vicinity of the excavation, are all examples of possibilities for mechanisms that will not be seen in laboratory tests on small specimens.

With only two situations available for comparison, i.e., the small-scale laboratory and the large-scale in-situ case, it will be very difficult to:

a. identify whether or not the differences in scale, geometry, and loading conditions of the two situations introduce, eliminate, or modify mechanisms and causes for deformation in one case compared to the other, and

b counter assertions that agreement between predictions based on laboratory tests and observed field results is a consequence of "curve fitting" (i.e., selecting arbitrary values of disposable variables in the constitutive relationship so as to optimize agreement with observations).

The possible effect of differences in scale and geometry could be investigated by an intermediate-scale experiment. The availability at WIPP of special equipment for drilling 36-in.-diameter horizontal holes into the salt would make such an experiment feasible, providing an opportunity both to assess specific mechanical properties (e.g., the in-situ modulus of elasticity of salt around the excavation), and to assess the effects of scale and geometry on the rate of closure of excavations in the salt. Observations on closure around a 36-in.-diameter hole would provide data on a scale intermediate between the current two situations (laboratory-scale and full-scale) and for a geometry that more closely resembles the full-scale excavation than the laboratory tests. It would also be possible to instrument the region adjacent to the (proposed) hole before it is drilled, thereby allowing determination of in-situ deformation behavior and its variation with time from the instant that the large hole is drilled.

Recommendation

Given that equipment is available underground at WIPP for drilling large diameter (one meter or so) boreholes into the salt, it seems feasible to undertake tests to observe time dependent deformations around such holes and to compare those predicted by the numerical model. The possibility of such tests has been explored with Sandia staff in discussions and visits to a possible site underground.

Figure 1 shows the site and test layout recommended on the basis of the discussions. In essence, a 36-in.-diameter, 100-ft.-long borehole would be drilled between two drifts in a 9-ft.-thick layer of uniform ("clean") salt at an elevation midway between two anhydrite layers. At this spacing the influence of the anhydrite layers on the deformation behavior of the borehole should be negligible. Installation of stress change and deformation gauges in the vicinity of the 36-in.-hole prior to coring should allow observation of all deformation, including the "early-time" deformation, resulting from drilling the hole. This early deformation was not observed in the full-scale tests.

Such a test has the following additional attributes that should help reduce the present uncertainties:

1. The salt being studied is not removed from its natural environment--as are the laboratory test specimens.

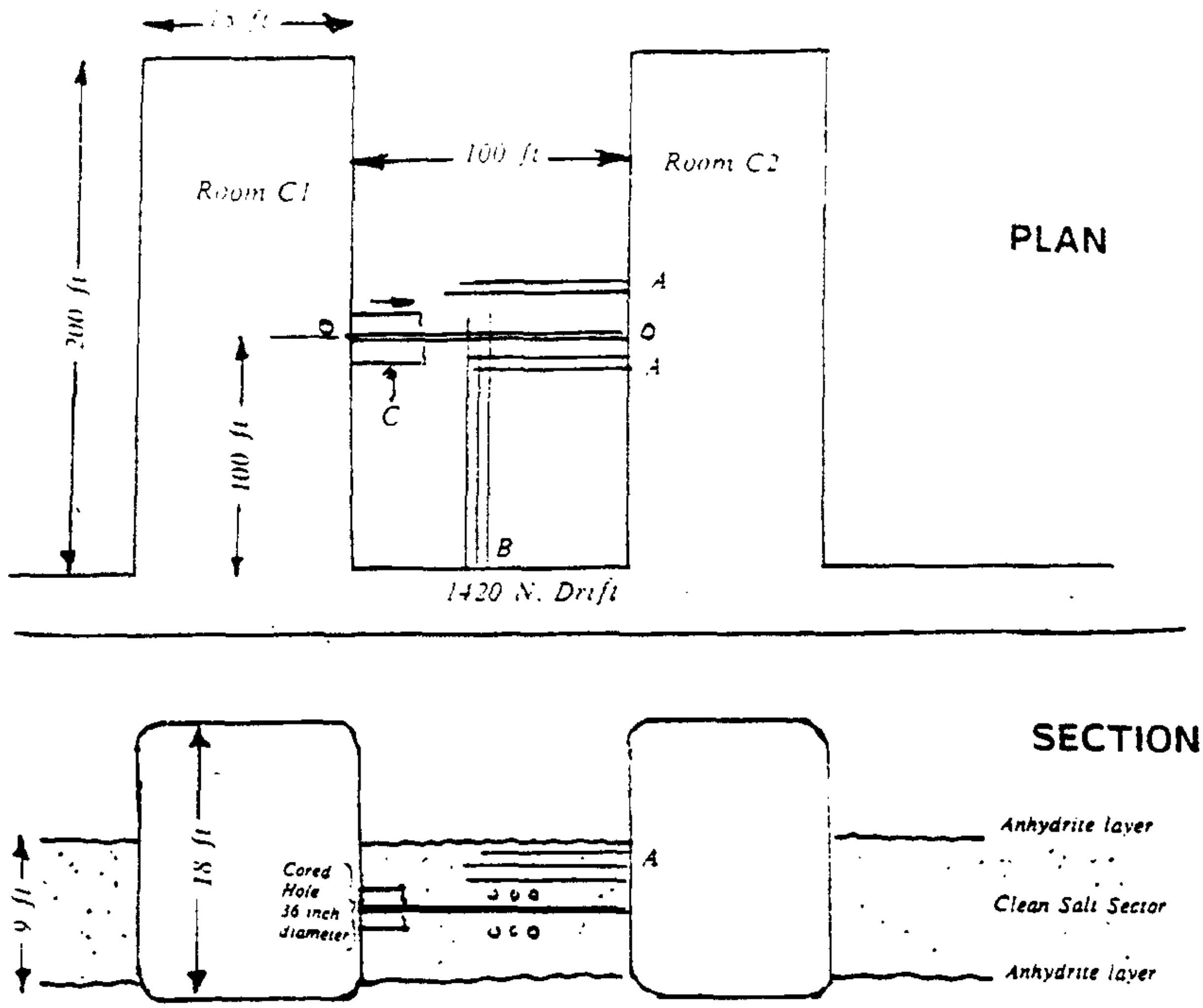

FIG 1. Recommended Layout of Intermediate Scale Time-Dependent Deformation Test

Test Procedure

Phase 1. (a) Drill one or more small diameter (2 to 3 inch) holes O-O horizontally between the two rooms. Instrument - to observe early deformations ahead of large coring drill as hole is being cored

(b) Drill three dimensional array of horizontal holes (A, B) at various heights [around path of (future) 36 inch hole] from Room C2 and 1420 N Drift, to observe stress changes and deformations induced in the vicinity of the large hole C as it is being drilled

Phase 2. Drill 36 inch diameter hole C horizontally from room C1 to room C2. Instrument to observe time dependent radial deformation imposed on the borehole. This deformation rate will be different at various cross sections due to the variation in stress concentrating effects of Rooms C1, C2,--hence several loading conditions can be simulated

2. There is no mechanical interface in the loading system.

3. The test is approximately one order of magnitude smaller in scale than the room excavation tests and one order of magnitude larger than the laboratory tests--so that it will allow evaluation of scale effects.

4. The test geometry is somewhat similar to that of the room excavation (long uniform cross-section) and the overburden pressure is comparable so that the three-dimensional stress conditions are reasonably similar. In both cases (room and borehole), the test scales are much larger than the salt grain size--so that scale effects due to the salt structure itself should be the same in the two cases. Salt structure scale effects may be significant in the laboratory test.

5. Anhydrite and clay seams occur within the region of stress redistribution around the full-size excavation. At the site recommended for the intermediate-scale experiment, the possibility of such influences on the time-dependent deformation around the hole is very much reduced.

Some Possible Outcomes of an Intermediate-Scale Experiment

- If the field/laboratory comparison for the intermediate-scale experiment proves to be essentially the same as for the full-scale tests (i.e., actual deformations 300% or so greater than numerical model predictions), then the differences are probably not the result of the volume of salt under high (deviatoric) stress, but more likely the result of the basic differences between laboratory and field testing procedures. The influence of differences in geometry between the cylindrical specimen tests and the field tests could be assessed by performing laboratory tests of radial creep behavior in thick hollow cylinders (e.g., 2-in. internal diameter, 10- to 12-in. outside diameter) subjected to external hydrostatic loading--this geometry would closely approximate that of the intermediate-scale test.

- If the intermediate-scale test results fall between those of the laboratory and field results, then it would appear that some form of scale effect is operative. This would indicate that more detailed laboratory studies of creep of uniaxially loaded solid cylinders will not suffice to explain the observed differences between field and laboratory behaviors. (The hollow cylinder laboratory tests mentioned above would help separate the influences of geometry and size on the result.)

- If the intermediate-scale results fall outside the range of the laboratory and full-scale results, it would again be important to assess the significance of test geometry (i.e., conducting laboratory hollow cylinder tests to allow comparison between tests of essentially similar geometries for the three existing series of tests). If the intermediate-scale results are still outside the range of the other tests, this would strongly suggest that removal of the salt from the original environment and preparation of test specimens significantly change the creep response. This would indicate that current understanding of the processes of creep in salt (and especially in laboratory specimens of salt) is inadequate to allow reliable prediction of the rate of closure of full-scale excavations from observations on laboratory specimens. In the case of the WIPP repository, this would imply that predictions of long- term excavation closures must rely on in-situ observations. The finding would also have considerable general implications, e.g., for cases where borehole cores only are available for testing (i.e., during site exploration, before direct underground access and testing are possible).

Thus, although of course results of the intermediate-scale tests cannot be anticipated, the tests do have the potential for providing important insights into the causes of the observed discrepancies between model predictions based on the laboratory tests and full-scale field observations.

Konrad B. Krauskopf

Konrad B. Krauskopf
Chairman, Panel on the
Waste Isolation Pilot Plant Project

NATIONAL ACADEMY OF SCIENCES

REVIEW COMMENTS ON DOE/WIPP 89-011 DRAFT TEST PHASE PLAN

July 19, 1989

REVIEW COMMENTS ON DOE DOCUMENT DOE/WIPP 89-011: DRAFT PLAN FOR THE WASTE ISOLATION PILOT PLANT TEST PHASE: PERFORMANCE ASSESSMENT AND OPERATIONS DEMONSTRATION

SUMMARY OF RECOMMENDATIONS

1. *DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of long-term safety of the WIPP repository, as currently understood.*

2. *Urgent attention should be given to (i) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (ii) examining options for modifications to the waste as part of the resolution of the gas generation issue.*

3. *Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5% by volume of the capacity of WIPP, are warranted and should begin without delay.*

4. *Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., U.K.) should be collected and studied, together with engineering modifications, as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.*

5. *The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.*

6. *Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.*

INTRODUCTION

Copies of DOE/WIPP 89-011 (full title: "Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration") were distributed in April to all members of the WIPP Panel for individual review. Topics for later discussion were selected by the Panel based on this review. The Panel assembled to consider the Draft on June 6-8 at the National Academy of Sciences (NAS) Green Building in Washington, DC. DOE staff and contractors made presentations and answered questions.

The Draft Plan (including the addendum dated June 16, 1989) proposes the underground emplacement of TRU waste equal to 2.7% by volume of the total design capacity of WIPP in the repository during the three-year period September 1989-September 1992 (Phase 1). This consists of 0.5% to be emplaced for experimental purposes and 2.2% for Operations Demonstration purposes. At the end of the three-year period DOE proposes to

> institute a holdpoint to analyze the results of the Performance Assessment and Operations Demonstration Programs up to that point. If, after a formal review of the results of the programs, there is reasonable confidence that WIPP will comply with the EPA Standard, 40 CFR 191, Sections 13 and 15 (as amended), and that Operations with actual TRU waste have been successfully performed in a safe and effective manner, a second part of the Test Phase will be undertaken. Test Phase activities and waste quantities for this part of the program

would be determined based on needs and requirements identified during the holdpoint review [DOE addendum (June 16, 1989)].

Several relevant documents (listed in Appendix A) were provided between the time of delivery of the Draft Plan and the WIPP Panel meeting; others were distributed at the meeting. These documents, together with the presentations and discussions during the June 6-8, 1989 meeting, yielded substantial information and insight on the proposed 5-year (Draft) Plan. Many of the conclusions and recommendations in the Panel's letter report are based on this more complete appreciation of the Plan.

PANEL FINDINGS

The Plan contains two principal sections, one entitled Performance Assessment, the other Operations Demonstration. The two sections will be discussed separately. The conclusions and recommendations are presented in *italics*; associated discussions are presented in standard type immediately following the particular conclusion or recommendation.

PERFORMANCE ASSESSMENT

Conclusions

Although the Plan is valuable in that it provides, for the first time, a comprehensive directory of all of the investigations, current or planned, under the WIPP program, and clearly indicates how these are related to the overall performance assessment activity, there are serious deficiencies in this Draft. In its present form, the Plan does not

(i) develop research priorities or identify critical problems;
(ii) identify or make appropriate use of the essential logic and rationale underlying the performance assessment process, i.e., the iterative, evolutionary selection and pursuit of investigations designed to establish the overall suitability of the WIPP site as a repository for safe, long-term isolation of TRU radioactive waste.

Failure to describe the iterative reassessment process and how it has been, and is being used at WIPP is a serious omission, since the entire program of experimental studies now underway, and many of those planned, have presumably been decided on this basis. From presentations made at this and other meetings of the NAS/NAE/NRC WIPP Panel it is clear that DOE and its contractors have, in fact, followed a process, albeit less well-defined and more intuitive than the formalized performance assessment system now under development.

Notably absent from the investigations described in the Plan is any consideration of the influences of radionuclide solubilities or engineered modifications on repository isolation performance. Although no details were provided, DOE and its contractors stressed, during the meeting, that engineered modifications are now being given serious attention as contributors to overall isolation performance. The Panel has long advocated consideration of the merits of engineered modifications to improve the waste isolation performance of the WIPP repository, if improvements should indeed be necessary.

While the performance assessment methodology described in Chapter 2.4, and illustrated graphically in Figure 2.4 (p. 2-21) of the Plan, seems to be appropriate for the formal assessment of compliance with 40 CFR 191, Sub-Part B (EPA Standard), it is unlikely that this methodology will have a substantial impact on the experiments planned, at least during the early part of the five-year Plan. It is also unlikely that the results of the experiments will be available for, or have any significant impact on, the performance assessment.

Recommendation 1

DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of the long-term safety of the WIPP repository, as currently understood.

The immediate purposes of such an assessment would be to

(i) identify critical risks and issues
(ii) articulate and document the rationale for currently proposed programs
(iii) establish priorities for these programs with respect to their expected contributions to the safe-repository objective (see Appendix)
(iv) stimulate early development of the iterative process of performance assessment priorities that is missing in the compliance-oriented "total system modeling" approach now being pursued (see Appendix).

The proposed assessment procedure would also complement the current performance assessment activities in the manner suggested by the Environmental Protection Agency (EPA) viz. in Appendix B, "Guidance for Implementation of Sub-Part B" [of 40 CFR Part 191] (Sept. 19, 1985).

> In making these various predictions [of overall disposal system performance] it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well. (Emphasis added.)

Additional discussion of Recommendation 1 is presented in the Appendix B to this report.

Recommendation 2

Urgent attention should be given to (i) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (ii) examining options for modifications to the waste as part of the resolution of the gas generation issue.

Considerable attention was given, during the meeting, to the suggestion in the Plan that the combined long-term effects of repository closure and gas generation due to corrosion of the waste package, and bacteriological and radiological decomposition of the TRU waste, could result in the development of gas pressures of the order of the lithostatic (i.e. overburden) pressure in the sealed repositories. Such pressures could give rise to potentially serious effects such as the generation of radial fractures, originating from the repository and able to propagate away from the repository, thereby allowing transport of radionuclides outside the repository. Computations suggest that the *intact* salt formations are likely to be essentially impermeable to gases; hence pressure leak-off may not occur.

On the other hand, it is possible that salt permeability may increase due to micro-fracturing caused by gas pressures (acting within the underground cavity) as they approach lithostatic pressure. This needs to be examined. Also, recent studies have revealed the development of circumferential fractures in the immediate vicinity of the underground excavations (the so-called "disturbed rock zone"). These fractures develop progressively as the excavations close, and may serve as high permeability paths along the periphery of the excavations. These paths would allow the gas to escape from the storage excavations as it is generated, at least until the fractures reheal due to creep closure around repository seals.

Studies have been started to examine the combined effects of gas generation, disturbed-rock-zone development, and engineered (chemical) modifications to the waste package on gas generation, long-term, in the overall repository environment. Laboratory, and perhaps in-situ, tests, even at a small-scale, to determine the gas permeability of intact salt as the pressure inside a "sealed" cavity approaches lithostatic pressure, would be very informative with regard to this problem.

Because the time necessary for gas pressure build-up to occur is considerably longer than the five-year period of the proposed DOE Plan, it is important that efforts be undertaken now that can reduce or eliminate concern that gas generation will affect safety. Such measures include changes in container materials, waste modification, and engineering modifications.

Underground Experiments

Conclusion

Determination of the rate, quantity, and composition of gases generated by the very heterogeneous mixtures of existing TRU wastes will require both laboratory (bench) and large-scale experiments, the latter involving assemblies of drums of TRU waste.

Recommendation 3

Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5% by volume of the capacity of WIPP, are warranted and should begin without delay.

Conclusion

Underground test results alone will not suffice for an early decision on appropriate strategies for addressing gas generation in waste package and underground emplacement, since much of the important data will still be accumulating at the end of the currently scheduled test phase (i.e., September 1991).

Recommendation 4

Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., U.K.) should be collected and studied together with engineering modifications as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.

The gases generated by the emplaced waste will be so low in radioactivity as to be considered non-radioactive. The processes by which gases are generated under repository conditions, including corrosion and radiolysis, do not produce radioactive isotopes. The repository gases should include only trace amounts of the noble gas fission products released from the wastes.

OPERATIONS DEMONSTRATION

Panel discussion of the need for demonstrating the ability of the WIPP facility to "be safely and effectively operated as intended by Congress in PL 96-164" [DOE statement of purpose of operations demonstration], was divided into two main topics:

1. Transportation and associated emergency preparedness issues (accident prevention, states training and education)

2. The need for early demonstration of operational readiness and pre-operational testing, including underground emplacement of TRU waste.

Transportation and Emergency Preparedness

Conclusion

The system proposed for transportation of TRU waste to WIPP is safer than that employed for any other hazardous material in the United States today and will reduce risk to very low levels.

The Panel was impressed with the WIPP program activities in transportation of TRU waste and emergency preparedness. The program is both very comprehensive and thorough, and will undoubtedly result in low levels of risk associated with surface transfer of TRU waste from current storage locations to the WIPP facility.

Recommendation 5

The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.

Panel members expressed concern that there was no indication, in either the Plan or the oral presentations, of a relationship between (a) the assessment of risk and safety associated with the various aspects of transportation of TRU waste and (b) the emergency planning and education program. Also, the 'high profile' and comprehensiveness of the states training and education program may give a false impression that TRU waste is more hazardous than a variety of other hazardous materials, some posing a significantly greater risk, that are routinely handled in the same states and on the same highways with no special precautions. In the Panel's view, the Department is being exemplary and responsible in giving a high level of attention to TRU waste transport. Such attention is appropriate for shipment of all hazardous materials, almost all of which pose greater risk than the TRU shipments.

Demonstration of Operational Readiness

Conclusions

Demonstration of operational readiness is an important phase of the overall WIPP program.

Pilot-plant and prototype testing are essential scale-up steps in the sound development of new technological systems. Given also the unique nature of the WIPP facility, such operations demonstration activities become particularly important. Transportation and underground emplacement of TRU waste on a pilot-scale are necessary parts of the overall demonstration that the WIPP facility can be operated safely for TRU waste isolation.

The overall public health consequences of the proposed operations demonstration are likely to be very small, given

(i) the low risks associated with transportation of TRU waste (discussed above), and
(ii) the inherently high security of the WIPP underground location, especially on a monitored storage basis, as is contemplated for the five years of the Plan.

Recommendation 6

Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.

The Panel discussed the desirability of starting the operations demonstration activities at the same time as the underground experiments. It was noted that significant waste handling experience will be gained by emplacement of the waste for the gas generation experiments.

Although it was acknowledged that early experience with operational activities (i) would expose, in a timely manner, problem areas that are manifested only in integrated plant operations, and (ii) could provide needed guidance on realistic alternatives between longer-term engineered isolation and permanent isolation options, there are important unresolved issues that could significantly affect the method of packaging and emplacement of TRU waste underground at WIPP.

These issues include, for example, (i) appropriate method(s) of dealing with gases generated from the waste containers stored underground; (ii) appropriate back-fill composition and back-filling procedures that may be considered necessary; and (iii) other engineering modifications that may prove necessary for the safe isolation of TRU waste.

DOE is, in fact, not yet ready or able to undertake a demonstration of operations as they will be conducted during waste emplacement for long-term isolation. As a consequence, the Panel does not consider in any detail the DOE proposed plans for operations demonstration.

APPENDIX A

DOCUMENTS DISTRIBUTED TO WIPP PANEL TO SUPPLEMENT DOE DRAFT PLAN (DOE/WIPP 89-011)

- Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant (2 vols) April 1989. DOE/EIS-0026-DS.
- Plan for the Disposal System Characterization and Long-Term Performance Evaluation for the Waste Pilot Plant SAND 89-0178 (by S.G. Bertram-Howery and R.L. Hunter) 1989.
- Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessment, Waste Isolation Pilot Project. (A. R. Lappin and R. L. Hunter, Editors); SAND 89-0462 April 1989.
- Draft Test Plan - WIPP Bin-Scale CH TRU Waste Tests TP-BIN1 5/8/89 (by Martin A. Molecke) May 1989.
- Test Plan - WIPP In-Situ Room-Scale CH TRU Waste Tests TPROOM1 6/05/89 (by Martin A. Molecke) June 1989.

No details were provided on plans for proposed laboratory experiments on gas generation. These are an essential complement to the proposed bin- and room-scale experiments. Details of the laboratory experiments would have allowed a more complete review of the bin- and room-scale tests. Also, the documents TP-BIN1 and TPROOM1 were distributed at the meeting in provisional, unreviewed draft form. Hence the primary source of information on the Bin- and Room-scale tests was the oral presentation by Dr. Molecke, and the Panel's conclusions were based on this presentation.

APPENDIX B

ADDITIONAL COMMENTS ON THE DEVELOPMENT OF COMPLEMENTARY APPROACHES TO PERFORMANCE ASSESSMENT

It is clear from reading 40 CFR 191 that EPA, in setting the Standard, recognized the difficulty of making precise quantitative predictions of the radionuclide releases from a given geological repository over periods of the order of 10,000 years or longer. In noting the merit of having "expert judgment" and "qualitative judgment" to assist in arriving at release estimates [See quotation in discussion of Recommendation 1, (Page 3)], EPA is acknowledging the uncharted and unprecedented nature of the computational task. The primary goal of 40 CFR 191 is to ensure that a repository poses no significant health risk to the public; the standards set for compliance represent EPA's best estimate of what is required to achieve this goal. To date, however, these standards have never been applied to a specific repository.

The Panel believes that the above-mentioned primary goal can best be achieved by focusing performance assessment activities on demonstrating that the WIPP repository will be *safe*, i.e, pose no significant risk to the public health and safety, rather than by an *uncritical*, formal adherence to compliance with the current EPA standard. The latter approach could result in neglect of possible long-term dangers or, conversely, unnecessarily detailed analyses of issues that can readily be shown to be of negligible consequence on simple qualitative grounds.

Clearly, it will be necessary to show compliance with the 40 CFR 191; and it is probable that the *"safe repository"* approach will lead to a design that is in compliance with the EPA standard. It is also probable that the experience gained by following this approach in the WIPP performance assessment process could lead to the identification of shortcomings in the present repository standards.

The recommended approach would be complementary to the present performance assessment effort, and it is anticipated that the initial effort of identifying critical issues and risks could be performed over a period of several days only. Division of the scenarios according to time periods (e.g., 10 yrs, 100 yrs, 1,000 yrs, 10,000 yrs) could illuminate the issues and risk management options. The scenarios are defined by (a) an initiating event (e.g., containment failure, gas generation, and fluid invasion); (b) undesirable consequences (e.g., fatalities and radionuclide release); (c) specific events that map (a) to (b). This approach forces an integration of the whole system and identification of the manner in which all components (hardware, procedures, software, and people) interact. The desired result is an *early* identification of the top several scenarios that currently appear most important on a risk basis. Simple bounding models, such as envisaged for this assessment, may well suffice to demonstrate acceptably low risk. Such models also have the advantage of being more comprehensible to the layperson than the complex models being developed for 40 CFR 191 Sub-Part B compliance purposes.

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COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

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NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF APRIL 1991
SUMMARY OF RECOMMENDATIONS

A Letter Report

by the

Panel on The Waste Isolation Pilot Plant

Board on Radioactive Waste Management

April 1991

Commission on Geosciences, Environment, and Resources
National Research Council

Washington, D.C. 1991

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A LETTER REPORT
BY THE
PANEL ON THE WASTE ISOLATION PILOT PLANT
BOARD ON RADIOACTIVE WASTE MANAGEMENT
NATIONAL RESEARCH COUNCIL/NATIONAL ACADEMY OF SCIENCES

SUMMARY OF RECOMMENDATIONS, APRIL 1991

INTRODUCTION

This letter report summarizes the views of the Panel on the Waste Isolation Pilot Plant (WIPP) on the status of the Department of Energy's (DOE) scientific and technical program to assess the WIPP's ability to isolate transuranic (TRU) waste and to demonstrate compliance with the relevant regulations.

For the summary, the Panel used as a point of departure its letter report of July 1989 which reviewed the DOE's draft plan for the WIPP's test phase. In the 1989 report, the Panel made six specific recommendations regarding the scientific tests, performance assessment progress, consideration of engineering alternatives to address some of the relevant issues, and operational readiness of the WIPP.

This report reviews the progress made in the WIPP program since the 1989 report, summarizes the responses made by DOE to the earlier recommendations, provides an overview of the Panel's views on the overall safety of the WIPP facility and presents some new recommendations to address unresolved issues.

RECOMMENDATIONS

1. Performance Assessment

o Since performance assessment calculations indicate that human intrusion into the repository is the scenario of dominant concern with respect to successful long-term waste isolation, the Panel recommends continued detailed study of the effects of human intrusion on repository performance.

o The U.S. Department of Energy (DOE) has made significant progress in the area of performance assessment procedures and should now extend these procedures to the engineered alternatives identified by the Engineered Alternatives Task Force (EATF). Application of performance assessment procedures is necessary to assess the merits of engineered modification of the waste form and/or the repository to address the issues of gas generation and human intrusion.

o DOE should be guided by performance assessment analysis, to the extent feasible, to determine a substantive basis for the long-term extrapolation of the repository behavior.

2. System Risk Analysis

o The various engineered alternatives should be assessed in terms of total system risk--including worker exposure, transportation and other risks--to evaluate the impacts on the entire transuranic (TRU) waste management system.

3. Experimental Program

Based on the results of performance assessment analysis, DOE should develop a well-designed experimental program and schedule that are sufficiently flexible to permit important scientific and technical issues to be addressed.

o The most recent sensitivity analyses suggest that the repository performance is affected significantly by radionuclide retardation in the rock strata above the repository. Intensive study of whether or not it is possible to determine reliable conservative estimates of field retardation coefficients for use in performance assessment is recommended. If retardation is found to be essential for adequate isolation of untreated TRU waste under the human intrusion scenario, for example, such studies could be crucial before a decision is made on the level of waste treatment that would be required.

o Understanding the nature of brine flow through salt over long time scales is important for determining the amount of brine likely to flow into repository excavations. DOE should continue the full-scale Room Q experiments with minimal interruption, together with intermediate-scale (900-mm-diameter) borehole inflow tests, since these experiments may provide conclusive evidence concerning the permeability of the repository salt to resolve the brine inflow question. DOE should give serious consideration to constructing another full-scale room for additional brine inflow studies, using the improved instrumentation, seals, and excavation equipment now available at the WIPP site.

o The likelihood of large volumes and pressures of gases being generated from the decomposition of TRU-contaminated waste in sealed repository excavations remains an important unresolved issue. The Panel is concerned that the bin experiments, which are designed to provide information about gas generation, are of such large scale and complexity that they might not yield significant gas generation data within an acceptable time frame. DOE should ensure that the effort and the resources devoted to the bin experiments do not impede other important experiments that may help to reduce significantly uncertainties in the assessment of repository performance.

4. Participation with the Scientific Community

o DOE should actively support vigorous international discussion of scientific and technical issues affecting repository safety, including gas generation. In addition, DOE should encourage critical review of the WIPP program through broader publication of its research findings in refereed scientific journals.

INTRODUCTION

As a part of a continuing effort to provide an objective scientific and technical evaluation of the Department of Energy's (DOE) program to determine the suitability of the Waste Isolation Pilot Plant (WIPP) as a repository for the safe permanent disposal of intermediate level transuranic (TRU) radioactive waste, the Board on Radioactive Waste Management's Panel on WIPP occasionally issues a status report on the WIPP's progress in addressing relevant scientific issues.

The last such report, issued in July 1989, commented on the U.S. Department of Energy (DOE) Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration. In commenting on this draft plan, the WIPP Panel addressed a number of important unresolved scientific and technical issues facing the WIPP Project and made six specific recommendations regarding the planned scientific tests, progress in performance assessment procedures and analysis, the need to consider engineering alternatives to address unresolved issues of potential gas generation and human intrusion, and the operational readiness of the WIPP.

The present report uses that 1989 report as its point of departure to comment on the progress made by DOE and its contractors in response to those recommendations, as well as to identify and comment on several additional issues.

Information about the progress made by DOE and its contractors was provided by quarterly briefings to the full WIPP Panel, supplemented by detailed periodic technical discussions between DOE contractors and specialists from the WIPP Panel.

The recommendations in the July 1989 Panel report are restated below, together with explanatory comments and discussions of relevant developments since the report was issued.

STATUS OF ISSUES ADDRESSED IN THE JULY 1989 RECOMMENDATIONS

Recommendation 1 (July 1989)

> **DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of the long-term safety of the WIPP repository, as currently understood.**

The concern behind this recommendation, as described in the July 1989 report, was that the WIPP Project was not making appropriate use of performance assessment to develop research priorities or to identify critical problems. In addition, the Project was not adequately pursuing performance assessment as an iterative, evolutionary process designed to investigate (1) the overall suitability of the WIPP site as a repository for the safe, long-term isolation of TRU radioactive waste, and (2) the possibilities for increasing the assurance of isolation by engineering modifications to the waste form and/or the repository. Since this recommendation was made, the performance assessment group at Sandia National Laboratory has made significant progress in

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performance assessment, and has done so following the iterative approach recommended.

The performance assessment studies indicate that (1) under the undisturbed condition, the repository is likely to meet all the performance requirements of the remanded U.S. Environmental Protection Agency (EPA) standard for radioactive wastes, and (2) human intrusion into the repository is the scenario of dominant concern. (The EPA standard, which was vacated by court order in 1987, has not yet been repromulgated by EPA, but EPA has informally circulated working drafts for comment.)

The Panel notes that geologic isolation of radioactive wastes was originally proposed, and historically has been developed, without the possibility of human intrusion as a primary consideration. Human intrusion differs from other repository isolation considerations for the WIPP in that it is the only one that "short-circuits" geologic isolation. The topic warrants continued study of methods to reduce the probability and consequences of human intrusion at WIPP. In addition, a critical reexamination of the human intrusion issue is needed, which should include analysis of the long-term probability, consequences, risk, and the overall responsibility to design deterrents to both inadvertent and intentional human intrusion. The human intrusion scenario is of concern for geologic repositories in general and is receiving attention in other countries as well.

The performance assessment studies for WIPP include a substantial effort to assess analytical uncertainties and sensitivities. The most recent sensitivity analyses suggest that the repository performance is affected significantly by radionuclide retardation in the rock strata overlying the repository, especially because of limited radionuclide solubilities. Under a human intrusion scenario, the adequacy of the repository to isolate the waste may be critically dependent on radionuclide retardation. (The July 1989 report noted that the DOE/WIPP Draft Plan lacked consideration of the influence of radionuclide solubilities on repository isolation performance.) Details of DOE work on radionuclide retardation will be presented to the WIPP Panel at a forthcoming meeting, so the Panel cannot now provide informed comments on how effective this work has been.

High priority should be given to applying performance assessment procedures to the engineering alternatives identified by the Engineered Alternatives Task Force (EATF). The EATF was established recently to develop and evaluate engineering methods for increasing repository safety. DOE is to be commended for responding to the Panel's concerns in this area, after the July 1989 letter report noted the absence of any consideration of engineered modifications on repository isolation performance. The methods identified by the EATF include modification of both the waste form and the repository design. The application of performance assessment analysis to various engineering alternatives is important to the appropriate consideration of each alternative and to DOE's decision whether or not to modify the waste and/or the repository. Although engineering modifications of the waste form might eliminate or substantially reduce gas generation, these modifications might also introduce significant additional risks of worker exposures to radionuclides and might have profound effects on costs and schedules. It is very important that the health effects associated with any proposed scheme of modification or those associated with the continued storage of waste in its present location be carefully examined in terms of the entire system.

The various engineered alternatives should be assessed in terms of total system risk--including worker exposure, transportation, and other risks--to evaluate the impacts on the entire TRU waste management system. A framework for looking at the risks of the overall system should start with consideration of the risks from storage, handling, treatment, transport, and disposal and should include consideration of the timing of waste disposal. The study should also consider costs and schedules of the various alternatives.

Overall, the Panel is impressed with the technical quality of the performance assessment analysis and with the amount of work done in a relatively short time. The Panel is concerned, however, that the present schedule leaves little opportunity for an iterative, evolutionary performance assessment process to be realized and that major elements of the repository evaluation are proceeding without the results of key experiments.

Recommendation 2 (July 1989)

> **Urgent attention should be given to (1) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (2) examining options for modification of the waste as part of the resolution of the gas generation issue.**

Theoretical analyses have been made of the combined influences of (1) gas generation, (2) repository room closure, and, to a lesser extent, (3) brine inflow into the rooms. These analyses indicate the following:

o Gas pressure of more than twice the lithostatic pressure could be reached and sustained indefinitely, assuming that gas is generated slowly (i.e., over several hundred years) in a very tightly sealed repository.

o As gas pressure rises, brine inflow would decrease correspondingly. (See also the paragraph below on Room Q findings.) This gas pressure increase would also result in some reenlargement of the rooms after the initial room closure (on the order of 300 years or so later).

o If the gas in the rooms could communicate with permeable layers in the salt, such as the anhydrite Marker Bed 139, the maximum expected volume of gas could be accommodated without exceeding lithostatic pressure. Rooms could be designed to ensure this communication. The rate and distance of gas flow would depend on the permeability of the anhydrite and on how the layers are connected to the rooms.

The Room Q experiments are short-term (i.e., 2- to 5-year) observations that may provide conclusive, fundamental evidence on the long-term behavior of the salt with respect to brine inflow. However, the Room Q experiments have not yet run long enough to provide definitive data. The Panel strongly recommends that the current Room Q experiments be continued without interruption, or with only minimal interruption as needed to improve the room seal. Additional intermediate-scale tests, including tests with 900-mm-diameter holes, should also be conducted to determine the brine inflow mechanism. Serious consideration should be given to the possibility of obtaining more conclusive information by conducting a second full-scale experiment using the improved instrumentation and seals now available for use on site. Carefully planned and instrumented to avoid the deficiencies of the Room Q Test – especially with respect to data on brine inflow in the early stages after excavation of the room – these tests could help corroborate (or contradict) the apparent very low permeability of the salt indicated by the Room Q experiments. There is still a fundamental question about the mechanism of brine inflow. Two hypotheses are put forward: (1) brine is released only from a disturbed zone around the room and (2) the brine represents Darcy-type flow from the far field. Every attempt should be made to resolve this fundamental issue.

As already noted, considerable uncertainty remains concerning the rate and volume of gas generation that might result from the waste emplaced underground at WIPP. However, recent results regarding brine inflow suggest that the amount of gas produced by corrosion may be substantially less than the theoretical maximum. It may also be possible that the environment could be conditioned to inhibit long-term biological gas generation.

If engineering modifications do not remove gas generation as a critical issue, or if performance assessment results do not indicate that WIPP performs acceptably for all plausible rates of gas generation, further progress in resolving important questions of gas generation will depend on the outcome of the laboratory and underground gas generation experiments currently planned. Given the relatively short times envisaged for these experiments (on the order of 5 years compared to repository gas generation times on the order of 300 years), it is prudent to prepare for the possibility that the results of the experiments may be inconclusive. This implies that studies by the EATF to seek practical measures for addressing the gas generation and gas pressure issues must be pursued vigorously and be closely associated with the performance assessment effort.

Recommendation 3 (July 1989)

> **Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5 percent by volume, of the capacity of WIPP, are warranted and should begin without delay.**

EPA has recently approved the no-migration variance petition submitted by DOE to allow these underground experiments. Efforts are under way at the TRU waste generator sites to characterize the waste to ensure that the waste placed underground for the experiment is a representative sample of the TRU waste to be stored in full-scale operations. These efforts are proving to be onerous for both scientific and regulatory reasons. To date, no TRU waste has been shipped to WIPP for the proposed bin- and room-scale experiments, and no realistic schedule for doing so has been proposed.

The Panel is concerned that the large scale and great complexity of the proposed bin experiments may result in significant uncertainties (which were noted above in the discussion of Recommendation 2) as to whether useful data will be obtained within an acceptable time frame. Great efforts are being made in some aspects of the planned experiments (e.g., in considering whether the bins contain statistically representative wastes), whereas in other aspects the experimental design is weak. The inability to sample brine to determine its composition in the bins throughout the experiments, for example, is a serious shortcoming that ought to be resolved. Overall, the Panel is concerned that the bin experiments are consuming more resources than anticipated, yet not progressing at a rate adequate to yield useful information within an acceptable time frame. If the bin experiments are to be completed as presently planned, it may be necessary to provide additional resources for other important parts of the program, such as radionuclide retardation, to be sure they are adequately supported.

Recommendation 4 (July 1989)

Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., UK) should be collected and studied together with engineering modifications as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.

Although significant information has been obtained from laboratory tests, no studies on gas generation from waste packages have been conducted to date. *Contacts have been established between DOE contractor scientists and their* counterparts in the United Kingdom. The gas generation problem in the geologic isolation of radioactive waste is now recognized in other countries. International discussions among scientists and engineers involved in the difficult technical issues of radioactive waste isolation is a vital and very cost-effective way of ensuring that the U.S. program incorporates the best and latest developments available worldwide and that programs in other countries benefit from experience in the U.S. program. The Panel again strongly urges the active support by DOE of vigorous international exchange, both on gas generation and on the variety of other scientific and technical issues of waste isolation. Further comments regarding the program of experiments appear below in the section Supplementary Comments.

Recommendation 5 (July 1989)

The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.

This recommendation reflected the Panel's view that steps taken to reduce the risks associated with transportation of TRU waste to WIPP were extraordinary in comparison to those steps taken for transport of other hazardous materials. A published comparison of the risks associated with transportation of other hazardous materials was suggested as a way to place the TRU waste transportation issue into better perspective. The Panel recently received a study from DOE of the risks associated with the transportation of other hazardous materials and is currently reviewing it.

Recommendation 6 (July 1989)

> **Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.**

DOE has the operational readiness demonstration part of the Draft Plan on hold, essentially as recommended by the July 1989 Letter Report.

SUPPLEMENTARY COMMENTS

In July 1989, the WIPP Panel expressed a major concern that the performance assessment of WIPP was not being used to identify critical issues that needed to be resolved in order to establish and demonstrate the long-term isolation capability of WIPP. DOE and its contractors have responded to this concern. Several critical issues have been identified either directly from the performance assessment studies or from studies in support of performance assessment. The long-term potential for gas generation by TRU waste in the repository and the radionuclide retardation capability of the Culebra formation are two such issues; human intrusion is a third.

Reduction of repository performance uncertainties associated with such issues will probably depend on the results of experiments, both in the laboratory and at the WIPP underground facility. The Panel is becoming increasingly concerned that, despite the vigorous and intensive efforts by dedicated staff, continuing delays in mounting the experiments may make them of little value in the current plan to determine whether or not the WIPP facility can meet the applicable EPA standards for waste isolation within the next several years. The Panel is, however, very reluctant to suggest that any currently proposed experiments be eliminated. The Panel is acutely aware that previous gas generation experiments, terminated reportedly because of budgetary constraints, would likely have provided information of significant value in current attempts to resolve gas generation questions.

The Panel is similarly aware that it advised against a proposed radionuclide retardation test in the Culebra formation some years ago. Although the Panel recognized that this was an important issue, it could not envision a field experiment that seemed likely to yield meaningful results. If the future performance assessment of human intrusion scenarios continues to indicate that radionuclide retardation in the Culebra formation is necessary to demonstrate that the EPA standards can be met, serious attention must be given to designing field experiments that can determine valid retardation coefficients. There is a considerable body of evidence to suggest that laboratory retardation values are not reliable indicators of retardation values in the field. It should also be noted that there are still unresolved issues with respect to the Culebra hydrogeology that add uncertainty to predictions of long-term flow and further complicate the assessment of radionuclide retardation in the Culebra formation.

A severe and pervasive difficulty in all of these issues is the need to make credible extrapolations (1) from laboratory- to field-scale behavior and (2) from information gathered over the short term to the long-term involved in repository performance. The Panel recommends that DOE avail itself of the expertise of leading members of the U.S. and international scientific communities, especially in microbiology and corrosion, to undertake (1) a thorough reexamination of its current strategy with respect to gas generation and (2) the demonstration of repository safety. These experts should address such questions as the following:

o How critical are the currently proposed gas generation experiments to the near-term (2-3 years) demonstration of compliance with EPA guidelines? DOE needs to be more aggressive in its efforts to resolve the issue of corrosion and microbial gas generation.

o Are there arguments based on fundamental principles of science that can be invoked as a basis from which to develop credible extrapolations predicting the volumes, pressures, and compositions of the gases generated over the long term under salt repository conditions?

o With respect to radionuclide retardation in the overall performance assessment of a repository at WIPP, what are reasonable assumptions and what evidence can be used to support those assumptions?

o Are reasonable engineering alternatives available that reduce or eliminate the need for experimental results on gas generation? The engineering alternatives work should be more closely coupled with performance assessment, so that the effectiveness of alternatives can be compared to the performance of the current reference design for WIPP.

DOE needs to work harder to understand gas generation and radionuclide retardation on the basis of the available information. Moreover, it is important for DOE to address human intrusion and repository performance in general, not just for WIPP. This issue is receiving increased attention abroad, and further work on this question is warranted.

As a further general observation, DOE should encourage critical review of the WIPP program through broader publication of its research findings in refereed scientific journals. This would give due recognition to the researchers involved, stimulate contributions from leading scientists worldwide, and bring greater overall credibility to the program.

The credible conclusion of this project requires careful and timely handling in a number of important issues: (1) a well-designed experimental program, (2) the establishment of a substantive basis for the long-term extrapolation of repository behavior, to the extent feasible, and (3) a schedule that is sufficiently flexible to allow changes to be made if important scientific and technical issues take longer to resolve than is currently anticipated.

In summary, the results that have been obtained since the July 1989 report (that is, those obtained from the assessment of undisturbed performance and the Room Q experiment) tend to support the view that WIPP can safely serve as a geologic repository for TRU waste. However, important issues such as human intrusion, gas generation, and radionuclide retardation remain.

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF JUNE 1992

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A Letter Report

by the

Panel on the Waste Isolation Pilot Plant

Board on Radioactive Waste Management

June 1992

Commission on Geosciences, Environment, and Resources
National Research Council

Washington, DC 1992

A LETTER REPORT
BY THE
PANEL ON THE WASTE ISOLATION PILOT PLANT

BOARD ON RADIOACTIVE WASTE MANAGEMENT
NATIONAL RESEARCH COUNCIL/NATIONAL ACADEMY OF SCIENCES

MAJOR CONCLUSIONS

Current performance assessment (PA) studies by the Department of Energy (DOE) indicate a high probability that the Waste Isolation Pilot Plant (WIPP) would perform successfully as a transuranic (TRU) waste repository. For some time, however, the panel has been concerned that questions identified as most critical by PA, particularly solubility and retardation, were not being given adequate or timely attention. The highest priority should now be given to conducting those tests that can determine the validity of the critical assumptions used in the PA calculations, especially the recently initiated solubility and dual porosity flow studies, and the proposed investigations on retardation in the Culebra.[1]

The February 1992 DOE/WIPP report[2] is a clear statement of the 15 critical information needs and associated experiments necessary to assess the long-term performance of the repository. However, the report fails to indicate how the results of the experimental program at all scales (laboratory, bin, alcove, and field tests) will be integrated to assess the long-term performance of the repository. DOE needs to articulate a convincing scientific rationale for the proposed test program in terms of the performance of WIPP as a TRU repository.

The panel has not been convinced by the scientific rationale, as presented, for the underground gas generation tests. In particular, the plan to conduct a large number of expensive bin tests and to terminate the experiments after five years has no discernible scientific basis. The possibility that the underground bin tests, as currently planned without brine sampling, will contribute to advances in the understanding of the overall long-term performance of a repository at WIPP is small.

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[1]The panel's conclusions and recommendations are underscored.

[2]WIPP Test Phase Activities in Support of Critical Performance Assessment (40 CFR 191B) Information Needs, February 1992. This report is referred to simply as the "February 1992 report" in this letter report.

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PANEL FINDINGS

Introduction

The panel reaffirms its conviction that performance assessment is the appropriate basis for setting priorities in the research and testing program for WIPP. In the panel's opinion, DOE is making excellent progress with its ongoing performance assessment efforts. For completing the studies, DOE lists 15 critical needs in Figure 1 of the February 1992 report. This figure is incorporated as Appendix A of this letter report, with a numbering of the items added for ease of discussion. In the following paragraphs several of these items are considered, followed by comments on the proposed experiments with real waste underground at WIPP.

Studies Requiring Highest Priority

Among the 15 critical information needs required to evaluate repository performance, the panel considers those associated with description of the natural barriers to radionuclide releases, i.e., retardation, solubility, and flow studies, to be the most important. The overriding importance of natural barriers is directly related to the need to consider the consequences of human intrusion, since performance assessment studies indicate that, without human intrusion, radionuclides can be contained safely within the Salado formation. The highest priority should now be given to conducting those tests that can determine the validity of the critical assumptions used in the PA calculations, especially the recently initiated solubility and dual porosity flow studies, and the proposed investigations on retardation in the Culebra.

The three specific information needs that the panel regards as most important are radioactive retardation data (item 1); dual porosity flow analysis (item 2); and radionuclide solubility/leaching data (item 12). The panel is impressed by the high quality of the initial studies in these three areas and urges that DOE continue to pursue them vigorously. As more details of the overall test program in these areas become available, the panel will be able to make more detailed comments. Currently, only a draft version of the laboratory solubility/leaching program (SAND 91-2111, M.L.F. Phillips and M.A. Molecke) has been reviewed; retardation experiments have only recently been started on a laboratory scale, and investigation of the feasibility of field-scale retardation tests in the Culebra dolomite is in the initial stages. If field tests are found to be feasible, the panel recommends that they be started as soon as is realistically possible, in view of the decade or longer that may be required for meaningful results.

Also, item 3 (Salado gas and brine flow data), including Room Q and related experiments, is important to an understanding of the basic nature of fluid flow at the site and to the selection of appropriate performance models.

Three of the critical needs (items 9, 13, and 14) are associated with gas generation and dissipation. Recent analyses suggest that gas generation could have beneficial effects on repository performance (e.g., retardation of brine inflow). Also, although the salt itself may be effectively impermeable, gas could dissipate into fissured anhydrite layers immediately above and below the repository. Overall, there is sufficient uncertainty in the magnitude and consequences of gas generation by TRU waste in a repository at the WIPP and in the likelihood of gas flow in fissured layers to warrant continued study of this issue.

Gas Generation Studies with Real Wastes

Of the 15 identified critical needs, only one, gas generation data (item 13), concerns the proposed experiments with real waste underground at WIPP. The February 1992 report presents a list of justifications, both technical and organizational, for conducting gas generation tests, especially the bin and alcove tests, at the WIPP facility (see pp. 2-23 to 2-27). The panel, however, has reservations about the need for all of the proposed tests. A discussion of these considerations follow.

(i) *Laboratory Experiments on Gas Generation*

Laboratory experiments on corrosion and microbial action are underway, but the studies are not yet complete enough to allow a reasonable prediction of the importance of either corrosion or microbial activity in the repository. It is not clear how these experiments can be used to determine gas generation rates under repository conditions. The duration of the experiments, two years or less, is much too short to obtain usable and defensible results. Also, there is no compelling scientific rationale for conducting these experiments at the WIPP facility.

(ii) *Bin Tests*

In terms of resources allocated, by far the major component of the current WIPP experimental program is the plan for underground gas generation experiments. Since the bins are loaded and sealed before being shipped to WIPP, the wastes do not come into contact with the WIPP environment, except with respect to temperature, and hence the tests could be conducted anywhere.

The panel emphasizes that it supports the notion of underground testing with TRU wastes, provided that the underground location does not prevent important tests from being carried out (e.g., the measurement of brine compositions in contact with real waste or progression of gas generation experiments without purging), and that the tests can be continued for sufficient time to provide useful information. The five-year duration proposed for the underground tests is likely to be shorter than is desirable for such tests.

- Dry bin tests

  Dry bin tests will not provide useful information regarding long-term gas generation in a TRU waste repository. A few dry bin tests may be of some value in developing experimental procedures as a precursor to wet bin experiments. The search for statistical reliability in the results of dry bin experiments has led DOE to propose about 60 dry bin tests. The panel considers this a serious misallocation of resources that could be much more effectively used in other parts of the WIPP Program.

- Wet bin tests

  The panel considers the proposed wet bin tests to be potentially the most informative of the underground test program, with respect to both gas generation and contaminant concentration in the brine. However, the panel is concerned that constraints on the tests may be imposed by the underground location. Specifically, purging of flammable gases could make the wet bin experiments unrepresentative of the behavior of actual waste in the repository. [We note that "new bin designs are being studied that will allow the gas compositions to evolve to whatever values the chemistry will allow" (February 1992 report, p. 2-23). Such bins would eliminate the need for purging.] If underground testing precludes sampling of brine in the wet bins, the tests should be done elsewhere, where brine could be sampled, and where tests could be continued for as long as useful data are being generated.

Based on a review of the roof reinforcement system installed in the proposed bin test room, and the associated monitoring program, the panel is confident that the test rooms, so reinforced, will be stable on the order of ten years or longer. It is essential that the monitoring program be continued.

(iii) *Alcove Tests*

Obviously, alcove tests can only be conducted underground. Plans for alcove tests have not yet been developed to the point where the panel can review them. Also, the February 1992 report indicates that ".. [the alcove] test program will occur if the laboratory and bin programs do not [suffice?] to satisfy the WIPP regulations that sufficient gas generation information is known for performance assessment." This statement clearly indicates that the alcove tests may not be carried out at all. In the absence of the alcove tests, only a very limited amount of radioactive waste will be required for the experimental program at WIPP.

In summary, the panel has not been convinced by the scientific rationale, as presented, for the underground gas generation tests. In particular, the plan to conduct a large number of expensive bin tests and to terminate the experiments after five years has no discernible scientific basis. The possibility that the underground bin tests, as currently planned without brine sampling, will contribute to advances in the understanding of the overall long-term performance of a repository at WIPP is small.

Plugs and Seals Test Plan

The panel has not reviewed the plugging and sealing test plan in sufficient detail to comment on the plan at this time. However, given that human intrusion (item 11) appears to be the only reasonable or possible cause of radionuclide release to the accessible environment at WIPP, the panel thinks that the performance of plugs and seals (items 5-8, and indirectly, item 10) is probably of secondary significance in the overall performance of the repository.

Document Re . .ew and Comment Form

Form Number: 430-A Effective 3/31/96

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-5	General	Yes	I am not confident from the information provided that I properly understand the nature and volumes of water flows in, around and through the shaft sealing systems. The time for system saturation remains unclear. This has bearing on the functionality of the shaft sealing system.	x		Clarification of the assumptions and conditions under which the repository would saturate will be added. If nothing is placed in the shafts and free flow of Rustler brines is allowed, the repository would fill in tens of years. With the seal system, as currently proposed, very little flow would enter the repository. These discussions will appear in the fluid flow analysis sections. In addition, the period required to resaturate the shaft will either be quantified explicitly or included generally, depending on advances in calculations.	X	

WASTE ISOLATION PILOT PLANT
Sandia National Laboratories

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	**Ref. Loc.**	**Mandatory**	**Comment**	**Accept**	**Reject**	**Reasoning**	**Accept**	**Reject**
MG-4	General	Yes	It is clear from the careful selection of the sealing materials that consideration has been given to their durability and longevity characteristics. However, in neither the preliminary nor the detailed documentation, are these issues discussed in detail. Durability and longevity issues present constraints that can also lead to the materials specifications. How have possible changes in material performance parameters with time (say over the period of 10,000 years) been applied to total system performance assessment modeling? Do short term effects influence long term performance? Mechanisms such as creep, fluid flow, microbiological degradation (and associated gas generation), seal material interactions, seal material-rock interactions, mineral transformation, silicification, dissolution and precipitation can all lead to changes in material and, hence, seal system performance characteristics. I suggest that the documentation should be expanded to provide confidence that these factors have been thoroughly considered as part of the generation of the sealing materials specifications and seal designs.	x		Substantiation will be added to the materials sections of the CSDR to support the current contention that longevity characteristics of the proposed materials are "as advertised". In particular, an "awareness" of concerns noted by the author will be demonstrated or identified and discussed in at least some detail based on information from the literature. Discussion of mechanisms such as creep, fluid flow and microbial degradation, seal material interactions and seal material/rock/brine interactions, mineral transformation and other issues raised by the reviewer will be expanded to address material change (or potential change) with time.	X	

Document Review and Comment Form

Form Number: 430-A   Effective 3/31/96

Procedure: QAP 6-3   Revision 1

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-3	General	Yes	With continuing regard to derived constraints and criteria, it appears that all of the seals, but particularly the clay (bentonite-based) seals are intended not only to limit the migration of brines and, particularly, possibly contaminated brines, but also to limit the migration of gases from the repository horizon to the biosphere. (Are these gases radioactive?). I understand that the proposed application of the clay seals as a barrier against gas movement is derived in major part from an in situ test carried out at the WIPP site. Experiments carried out at the University of Manitoba (Kirkham, 1995) tend to confirm the results of the in situ tests in that 25 mm thick specimens of water saturated compacted bentonite (g_d~1.3 Mg/m^3) resisted breakthrough pressures of up to 10 MPa. Similar results have been obtained from experiments in Japan (Hara, personal communication). A general rule of thumb seems to be that gases break readily through bentonite layers when and if the degree of saturation decreases below about 80 to 85 %. This rule is conventionally applied in the modeling of oil and gas reservoirs. These results conflict with conventional published wisdom (Pusch, 1985) which suggests that gas breakthrough pressures are related to bentonite swelling pressure. This is an area of concern and question and discussion of the uncertainty and it's effects on the materials specification, associated design assumptions (such as those regarding the rate of resaturation of the clay barriers and the rate of gas generation) and the method of clay seal emplacement are absent from the design documents (both preliminary and detailed). With regard to the method of seal emplacement it is currently proposed that the clay seals should be placed as precompacted blocks. The effects of joints between the blocks need to be considered. During design refinement activities, the method of deep dynamic compaction investigated and proposed for placing the salt seals should be considered as a method for the generation of homogenous almost saturated bentonite seals (see item 1 above). The use of bentonite-salt (sand-sized) mixtures should be considered as a possible alternative to the currently proposed 100% bentonite seals.	X		Further substantiation of bentonite as a gas barrier will be provided in construction and materials appendices. In particular, suggestions of the reviewer will be incorporated to add confidence that a gas barrier is obtainable upon construction. Additional documentation drawn from sources identified by the reviewer will be sought to establish gas permeability and breakthrough performance. Further text identifying assumptions of rates of gas generation and resaturation of the clay barriers will be added in the appropriate sections of the design documents. *Text and basis for dynamic* compaction construction alternative will be added. Discussion, such as use of sand additive to bentonite as a means to compact the material to densities approaching 95%, saturation will be added. We propose to leave the construction method for the clay column as blocks with further development of the basis for dynamic compaction.	X	

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-2	General	Yes	I have a general and abiding concern with the relationships between derived design constraints and criteria as they relate to materials specifications. I understand that, generally, the materials specifications have been made to provide constructable seal elements with as minimum as practical permeability and that the properties of *the as-placed materials have been* incorporated into total system performance assessment models. The derived design criteria were not clear to me from either the documentation provided or the presentations made. From the data provided, it appears that all of the sealing materials being proposed for use ensure that chemical diffusion is the dominant mechanism of radionuclide transport in a possibly saturated repository at WIPP (see, for example, J.K. Mitchell, 1992). Is this usable as a derived criterion for the specification of the sealing systems?	x		While the use of low permeability materials approach conditions where diffusion could be the dominate transport mechanism, we don't believe such a condition can be invoked advantageously to a seal design criterion. By severely limiting brine flow, we place a de facto limit on nuclide migration. We propose *to leave the language as a* discussion of "low flow" and not of contaminate migration.	X	

WASTE ISOLATION PILOT PLANT Sandia National Laboratories	# Document Rev..w and Comment Form **Form Number: 430-A Effective 3/31/96**
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Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-1	General	Yes	Many of my previous concerns related to the constructability of the sealing systems. I was impressed by the amount and rigour of work that has been carried out to confirm the constructability of the seals and I am satisfied that the design that I understand will be proposed in the detailed design document will be workable within the constraints of existing engineering practice or reasonably simple extrapolations therefrom. To provide absolute confidence in the constructability of the proposed sealing systems it will be necessary, with time, to effect programs which demonstrate the practicality of the extrapolated technologies	x		Construction procedures and associated design modifications consistent with review comments and discussions with panel member Steve Phillips will be completed in preparation of the CSDR. While we concur with the author's opinion that future work will increase confidence in the sealing methods, recommendations for such work will not appear in the report itself, but constitute the types of alternatives or options to be considered in future design refinements.	X	

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	Procedure: QAP 6-3 Revision 1 **Page 1 of 8**

This form may be used for test plans, procedures, reports, design packages, abstracts, Technical Operating Procedures, and other documents.

Section of document to be reviewed and review criteria: (See sample criteria in QAP 6-3.).

Review Requester: Robert Stinebaugh Date: 4/24/96 Response Prepared By: Donald D. Hansen (Signature of Author/Designer) Date: 4/26/96

Reviewed By: H. N. GRAY Date: 4/26/96 Response Concurrence: M K Gray Date: 4/26/96

Review Type: ☒ Independent Technical ☐ QA ☐ Management

☐ Other Specify:

Title of Document to be Reviewed: Waste Isolation Pilot Plant Sealing System Design Review

☒ Pre-Publication ☐ Post-Publication

Signature of Reviewer Signature of Reviewer

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject

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SUMMARY STATEMENT
BY STEVE PHILLIPS

The seal design uses existing technology and materials that have reasonably proven track records of durability. The redundancy in the design provides added assurance to mitigate against those areas where some uncertainties still exist and it is possible that all these will never be completely resolved.

It is considered improbable that the seal design, as presented including the revisions recently discussed, can be significantly and practically improved within the limits of existing construction materials and technologies, except in some areas where optimization of materials and methods of emplacement can be achieved.

The design, as presented, with modifications as discussed and documented April 24 - April 26, 1996, are likely to meet the general requirement of very low flow in and around the shafts. Over the next years, and prior to the emplacement of the seals at the WIPP site, new technology and materials will undoubtedly become available to provide additional improvements and added confidence in the shaft sealing.

Steve Phillips.

will meet design guidelines beyond the broad PA analyses performed to date on an equivalent "generic" design which does not account for any performance allocation amongst the system components. The seal system has been conservatively designed with what is considered to be the best available technologies, materials and construction procedures. If the design does not quantitatively meet the performance requirement, then it might be necessary to consider adopting the use of new technologies, materials or procedures.

In regards to whether the design can be implemented, it is my opinion that the seal system can be constructed as set forth. The concepts and procedures selected are not unusual compared to industrial construction practices. Suggestions have been made for minor enhancements focusing on ensuring emplaced material properties can be attained.

4/26/96

SUMMARY STATEMENT
BY JOHN TINUCCI

The design that has been put forth presents one way of efficiently sealing shafts. Recognizing that other ways could also be made to work, the design presented here is similar to other suggested by the scientific community for sealing deep geologic nuclear waste repositories. The concepts presented have been developed from sound engineering judgment and sound analyses techniques. The anticipated performance of individual sealing components are within reasonable expectations based on currently available field and laboratory data, albeit limited. To address the wide scale of uncertainties, the design has been conservatively laid-out with redundant multiple-barrier components so that the overall seal system performance is not dependent on the functionality of an individual component. The design as it exists today is a conceptual design since it describes basic concepts and provides sufficient backup analyses to demonstrate that those concepts will reasonably satisfy the qualitative design guidelines.

In the review process several issues were raised where minor enhancements to the design might provide better confidence in the overall performance of the system, especially in the short-term where performance is critical. These suggestions included investigating the use of grouts around SMC concrete plugs, complete removal of the liner in the Rustler formation, dynamically compacted clay column, repressurizing asphalt waterstops, etc.

It is my opinion that the Performance Assessment portion of the waste disposal program dealing with Seal System Performance has a shortcoming in that it has not assigned a target performance range for developing designs, at least as put forth in the documentations. It is recognized that the conceptual design has been developed for all 4 shafts but analyses limited to single isolated (AIS) shaft. However, the designers are unsure of how quantitatively this design

The materials being used to form the seals are the same as those being suggested in the scientific and engineering literature as appropriate for sealing deep geologic repositories for radioactive wastes. When constructed as proposed, it is likely that the shaft seals will ensure that water flow rates from the repository level to the biosphere will be very low within the seals and in the immediate vicinity of the sealed shafts. In some places the shaft seal designs being proposed appear to be excessively complex. It is likely that simplification of the design and material placement methods will lead to a more constructable sealing system without compromising system performance.