Improving Operations AND Long-Term Safety OF THE Waste Isolation Pilot Plant

Final Report

Committee on the Waste Isolation Pilot Plant
Board on Radioactive Waste Management
Division on Earth and Life Studies
National Research Council

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Cover: The four drawings on the left represent the natural process of salt encapsulating transuranic waste drums in the WIPP repository. From top to bottom, the chronological sequence is 0 years, 10-15 years, 50 years, and 1,000 and more years (Hansen et al., 1997). Reproduced with permission. The image in the center shows a sample of Permian age salt crystals, about 225 million years old, taken from the WIPP excavations. The picture on the right shows typical scenery in proximity to the WIPP repository.

Back cover: Picture of three trucks transporting transuranic waste to the WIPP. *Source:* DOE.

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Finally, the committee wishes to thank Barbara Pastina, Angela Taylor, and Kevin Crowley, staff of the National Research Council's Board on Radioactive Waste Management, Thomas Kiess, former staff officer and study director, and Elizabeth Ward of Garrick Consulting for great team effort to support this project.

List of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Ray Chamberlain, Parsons Brinckerhoff, Inc.
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Frank L. Parker, Vanderbilt University. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Preface

This study was sponsored by the U.S. Department of Energy (DOE) Carlsbad Field Office, formerly known as Carlsbad Area Office (CAO). To accomplish this project, the National Research Council (NRC) empanelled a 15-member committee on the Waste Isolation Pilot Plant (WIPP). Committee members were chosen for their expertise in relevant technical disciplines such as nuclear engineering, health physics, chemical and environmental engineering, civil and transportation engineering, performance assessment, analytical chemistry, materials science and engineering, plutonium geochemistry, hydrogeology, rock and fracture mechanics, petroleum engineering, and mining engineering. The committee is operated under the auspices of the Board on Radioactive Waste Management of the NRC.

The first committee on the Waste Isolation Pilot Plant was formed in 1978, at the request of the DOE, to provide scientific and technical evaluations of the investigations at the WIPP. That committee functioned as a standing committee until late 1996 at which time it published its final report (NRC, 1996a), *The Waste Isolation Pilot Plant, A Potential Solution for the Disposal of Transuranic Waste.*[1] This was the last report of the committee prior to certification of the site. The committee concluded that "human exposure to radionuclide releases from transuranic waste disposed in the WIPP is likely to be low compared to U.S. and international standards." The report went on to say, "The only known possibilities of serious release of radionuclides appear to be from poor seals or some form of future human activity that results in intrusion into the repository." The report recommended that "speculative scenarios of human intrusion should not be used as the sole or primary basis on which to judge the acceptability of the WIPP (and, by extension, any geological repository)."

Following the publication of the 1996 report, this WIPP committee was created to carry out the statement of task reported in Sidebar P.1. The committee has produced two reports to cover the statement of task, an interim report published in April 2000 and this final report. The complete interim report has been reproduced as Appendix A1.

[1] Transuranic (TRU) waste is waste contaminated with alpha-emitting radionuclides of atomic number greater than 92 and half-lives greater than 20 years in concentrations greater than 100 nanocuries per gram. For more details see Sidebar 1.2 and the glossary.

Sidebar P.1 Statement of Task

The purpose of this study is to identify the limiting technical components of the WIPP program, with a twofold goal of (i) improving the understanding of long-term performance of the repository and (ii) identifying technical options for improvements to the National Transuranic (TRU) Program (i.e., the engineering system that defines TRU waste handling operations that are needed for these wastes to go from their current storage locations to the final repository destination) without compromising safety.

To accomplish this goal, the study will address two major issues:

1. The first is to identify research activities that would enhance the assessment of long-term repository performance. This study would examine the performance assessment models used to calculate hypothetical long-term releases of radioactivity, and would suggest future scientific and technical work that could reduce uncertainties.

2. The second is to identify areas for improvement in the TRU waste management system that may increase system throughput, efficiency, cost effectiveness, or safety to workers and the public. This study will examine, among other inputs, the current plans for TRU waste handling, characterization, treatment, packaging, and transportation.

In October 2000, the DOE provided a comprehensive response to the recommendations made in the interim report. The response is reported in Appendix A2. The committee is very encouraged by the quality of the responses and the actions the DOE is taking. Although the responses will not have a full impact on this final publication because of the report's tight schedule, the committee has been able to acknowledge a number of them in this report.

As is the normal practice of the National Academies, committee members do not represent the views of their institutions but form an independent body to author the report using the information gathered together with their collective knowledge and experience. The report reflects a consensus of the committee and has been reviewed in accordance with NRC procedures.

B. John Garrick, *Chair*
Committee on the Waste Isolation Pilot Plant
April 2001

Contents

Executive Summary

The Waste Isolation Pilot Plant (WIPP) is a deep underground mined facility for the disposal of transuranic waste resulting from the nation's defense program. Transuranic waste is defined as waste contaminated with transuranic radionuclides with half-life greater than 20 years and activity greater than 100 nanocuries per gram. The waste mainly consists of contaminated protective clothing, rags, old tools and equipment, pieces of dismantled buildings, chemical residues, and scrap materials. The total activity of the waste expected to be disposed at the WIPP is estimated to be approximately 7 million curies, including 12,900 kilograms of plutonium distributed throughout the waste in very dilute form. The WIPP is located near the community of Carlsbad, in southeastern New Mexico. The geological setting is a 600-meter thick, 250 million-year-old saltbed, the Salado Formation, lying 660 meters below the surface.

The National Research Council (NRC) has been providing the U.S. Department of Energy (DOE) scientific and technical evaluations of the WIPP since 1978. This is the first full NRC report issued following the certification of the facility by the U.S. Environmental Protection Agency (EPA) on May 18, 1998. An interim report was issued by the committee in April 2000 and is reproduced in this report as Appendix A1. The main findings and recommendations from the interim report have been incorporated into the body of this report.

The committee's task is twofold: (1) to identify technical issues that can be addressed to enhance confidence in the safe and long-term performance of the repository and (2) to identify opportunities for improving the National Transuranic (TRU) Program for waste management, especially with regard to the safety of workers and the public. The complete statement of task is reported in Sidebar P.1 of the Preface.

The **overarching finding and recommendation** of this report is that the activity that would best enhance confidence in the safe and long-term performance of the repository is to monitor critical performance parameters during the long pre-closure phase of repository operations (35 to possibly 100 years). Indeed, in the first 50 to 100 years the rates of important processes such as salt creep, brine inflow (if any), and microbial activity are predicted to be the highest and will be less significant later. The committee recommends that the results of the on-site monitoring program be used to improve the performance assessment for recertification purposes. These results will determine whether the need for a new performance assessment is warranted. For the National TRU Program, the committee finds that the DOE is

implementing many of the recommendations of its interim report. It is important that the DOE continue its efforts to improve the packaging, characterization, and transportation of the transuranic waste.

The committee's **specific findings and recommendations** have been grouped into three categories: (1) site performance, (2) site characterization, and (3) the National TRU Program.

SITE PERFORMANCE

Every five years, the WIPP must obtain recertification from the EPA by showing that the repository is performing as predicted. Site performance refers to activities, phenomena, or events that occur as a result of repository construction and waste emplacement in the time frame between placement of the waste and final sealing[1] of the repository shaft. Site performance has been evaluated by the DOE in its Compliance Certification Application (CCA) (DOE, 1996). The CCA relies on a model, called a "performance assessment," that calculates the probability and consequence of several scenarios by which radionuclides could be released into the environment. The performance assessment also identifies the major uncertainties and their impact on the overall performance of the system. To reduce some of the uncertainties in the performance assessment and to add confidence in the containment performance of the repository, *the committee recommends taking advantage of the long (35 to possibly 100 years) pre-closure operating period to monitor selected performance indicators,* including those listed below:

1. Brine migration is a key issue because it provides the most realistic mechanism for mobilizing and transporting radionuclides from the waste. The mixing of brine and waste could also result in the generation of gas in the repository. **The committee recommends pre-closure monitoring to gain information on brine migration and moisture access to the repository. Observation should continue at least until the repository shafts are sealed and longer if possible. The committee recommends that the results of the on-site monitoring program be used to improve the performance assessment for recertification purposes.**

2. Gas pressure generation is an important issue in the assessment of human intrusion scenarios. In the committee's opinion, there are uncertainties in some of the assumptions about gas generation used in the performance assessment of the CCA. **The committee recommends pre-closure monitoring of gas generation rates, as well as of the volume of hydrogen, carbon dioxide, and methane produced. Such monitoring could enhance confidence in the performance of the repository, especially if no gas generation is observed. Observation should continue at least until the repository shafts are sealed and longer if possible. The results of the gas generation monitoring program should be used to improve the performance assessment for recertification purposes.**

3. Magnesium oxide (MgO) is used as backfill in WIPP to provide some control of the chemical environment of the waste and, to a lesser extent, to fill voids in the disposal locations, thus enhancing the healing process. The chemical performance of MgO depends on gas generation and brine inflow as well as other chemical processes taking place in the repository. The committee finds that there is uncertainty about the effectiveness of MgO in controlling the chemical environment of the waste. Therefore, **the**

[1] The terms "sealing" and "healing" are both used in this report in relation to the repository. Repository sealing refers to the emplacement of engineered barriers preventing access or leakage to and from the repository. Repository healing indicates a natural process by which the mined salt creeps in around the waste to fill all the void spaces in the repository. See also "salt creep" and "engineered barriers" in the Glossary.

committee recommends that the net benefit of MgO used as backfill be reevaluated. The option to discontinue emplacement of MgO should be considered.

4. Deformation of rock salt and interaction of salt with TRU waste containers are of interest as a part of the pre-closure performance confirmation. The creep of salt is expected to entomb the waste drums in 100 to 150 years; thus, the radionuclide mobility values used in the performance assessment might have been overestimated. This implies less migration of radionuclides from the repository into the environment. **The committee recommends pre-closure monitoring of the status of room deformation and of the disturbed rock zone[2] (DRZ) healing. Seal performance should also be assessed. Observation should continue at least until the repository shafts are sealed and longer if possible. The results of the monitoring of room deformation and DRZ healing should be included in the PA and used for recertification purposes.**

SITE CHARACTERIZATION

The WIPP program has engaged in a comprehensive program of site characterization that, in general, has been adequate to support certification of the facility. *The committee identified four areas in which additional site characterization or monitoring is recommended.* The four site characterization programs are described below:

1. A program for the hydrologic characterization of the Culebra, the most transmissive unit in the Rustler Formation. The Culebra could provide a pathway for the release of radionuclides into the environment in the event of human intrusion. **The committee recommends a monitoring program to characterize the geohydrology of the Culebra Dolomite. Tests and measurements that should be considered include angled boreholes, natural gradient tracer tests, and additional pump or injection tests. These new data should be used to confirm, or modify, the conceptual and numerical models now proposed as reasonable simulation of the actual system.**

2. A program for the detection of deep brine reservoirs below the waste disposal horizon. To improve site characterization and increase confidence in repository performance in view of the recertification application, **the committee recommends the use of seismic survey techniques for detecting large brine reservoirs below the repository.[3] In case a brine reservoir were found beneath the WIPP and its size were larger than what is already taken into account in the PA, then the DOE should conduct an extensive review of the impact of such reservoir on the repository performance. A basis would then exist to take appropriate action to ensure the safety of the repository.**

3. A program for monitoring oil, gas, and mineral production in the area. Oil, gas, and mineral extraction activities in the vicinity of the repository could threaten its integrity. **The committee recommends the development of a database to collect information on drilling, production enhancement,**

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[2] The disturbed rock zone is the zone around an excavation, in the host rock salt, where the stress field has been modified sufficiently to cause the formation of microfractures in the rock salt.

[3] The committee recognizes that small brine reservoirs, including brine occurring as a saturated continuum, could not be detected by seismic surveys, or other noninvasive remote sensing techniques.

mining operations, well abandonments, and unusual events (accidents and natural events) in the vicinity of the WIPP site.

4. A program for establishing the baseline for naturally occurring radioactive material (NORM) in subsurface brines and hydrocarbons in the vicinity of the site. The NRC interim report recommended that the DOE develop and implement a plan to sample oil-field brines, petroleum, and solids associated with current hydrocarbon production to identify the background concentrations of naturally occurring radioactive material in the vicinity of the WIPP site, for baselining purposes. In response to this recommendation, the DOE has started to collect data and is developing a database on NORM. **The committee recommends that the DOE continue the implementation of its plan to sample oil-field brines, petroleum, and solids associated with current and future hydrocarbon production, as necessary to assess the magnitude and variability of NORM in the vicinity of the WIPP site for baselining purposes.**

THE NATIONAL TRU PROGRAM

The National TRU Program, administered by the DOE Carlsbad Field Office, is a program to accommodate all applicable external regulations and internal requirements that are associated with the characterization, certification, packaging, and transportation of TRU waste to the WIPP facility. The committee addressed two main issues pertaining to the National TRU Program: (1) waste characterization and packaging and (2) waste transportation.

Waste Characterization and Packaging

The committee reviewed some of *the waste characterization and packaging requirements* established by the National TRU Program from a safety and cost point of view. This issue was detailed in the committee's interim report. A new issue concerning the *total inventory of organic material allowed in the repository* surfaced after the committee visited the WIPP site.

1. Waste characterization and packaging requirements. A principal finding of the interim report (Appendix A1) was that many requirements and specifications having to do with waste characterization and packaging lacked a safety or legal basis. In fact, the committee concluded that some of the requirements penalized the program by adding unnecessary costs and safety risks. Examples of self-imposed waste characterization requirements are waste repackaging to dilute the hydrogen-producing components and visual examination to verify the content of waste drums and avoid miscertifications. Therefore, the committee recommended in the interim report that the DOE should eliminate self-imposed waste characterization requirements that lack a safety or legal basis. The DOE has responded to this recommendation by initiating a review of all waste characterization and packaging requirements (Appendix A2). **The committee recommends that the DOE's efforts to review waste characterization and packaging requirements continue and that changes be implemented over the entire National TRU Program. The committee recommends that the resources required to complete these improvements be made available by the DOE.**

2. Total inventory of organic materials allowed in the repository. Buried with the waste is a considerable inventory of organic materials, such as plastic film used to stabilize the drums, plastic bags and corrugated cardboard, wooden waste boxes, plastic liners of waste drums, and pressed wood "slip sheets."

The principal concern of the committee is that the DOE does not appear to keep an accurate inventory of such organic material. **The committee recommends a risk-based analysis of the total organic material regulatory limits in WIPP. If accounting for the organic material is important to the safety of the repository, an inventory record system should be implemented as soon as possible to provide a basis for meaningful safety analysis.**

Waste Transportation

The committee has examined various aspects of the WIPP TRU waste transportation system, focusing on system safety and the cost-effectiveness of planned and ongoing activities. In its interim report (Appendix A1), the committee reviewed DOE's TRANSportation Tracking and COMmunication (TRANSCOM) system and its emergency response program. In addition to the *DOE's communication and notification program* and its *emergency response training,* two other issues have been revisited in this report: the potential use of *rail as a transportation option for certain TRU waste,* and *gas generation safety analysis for Transuranic Package Transporter, Model II (TRUPACT-II) containers.*

1. DOE's communication and notification program. The committee's interim report (Appendix A1) reviewed the transportation system for WIPP waste and particularly addressed the issue of the DOE's communication and notification system TRANSCOM and its emergency response program. The committee raised questions about the reliability and ease of use of the TRANSCOM system. Meanwhile, the DOE appears to be moving systematically toward the implementation of an efficient, comprehensive, and state-of-the-art communication and notification system, called TRANSCOM 2000. **The committee recommends that the DOE implement as soon as possible the new TRANCOM 2000 communication and notification system. Moreover, because the human factor is an important element of transportation system quality, TRANSCOM 2000 should include methods to minimize the occurrence and impact of human errors.**

2. DOE's emergency response training. Although the committee is aware of the fact that the DOE is not directly responsible for the emergency response program, DOE should nevertheless identify the resources (e.g., responders, medical facilities, recovery equipment, response teams) that might be necessary to respond to a transportation incident. **The committee recommends that the DOE facilitate the involvement of states in developing and maintaining an up-to-date, practical, and cost-effective spatial information database system to coordinate emergency responses. The DOE should also develop an ongoing assessment program for states' emergency response capabilities and allocate training resources to address deficiencies in coverage along WIPP routes.**

3. Rail as a transportation option for certain TRU waste. Among the generator sites, some have rail-loadings and tracking capabilities that could be used for railway shipping of TRU waste to WIPP. The objective of the following recommendation is to minimize the number of road shipments, and therefore the related risk, and to optimize the waste load for shipments of inner waste packages that are unsuitable for placement in TRUPACT-II overpacks. **The committee recommends that all reasonable transportation options including reduction in the number of shipments, such as rail and road transportation with better-adapted containers, should be part of the decision-making process of transporting TRU waste from generator and storage sites to the WIPP. Future transportation studies should consider railway shipments and their impact on both the safety and the cost of the program. The**

DOE should also continue to pursue the development of packaging alternatives for materials not suitable for TRUPACT-II containers.

4. Gas generation safety analysis for TRUPACT-II containers. Hydrogen gas is generated in the shipping containers by radiolytic decomposition of the organic materials in waste during transportation of TRU waste to the WIPP. The root issue is the interpretation of the U.S. Nuclear Regulatory Commission's (USNRC's) regulations on shipments involving possible flammable gases. The questions of interpretation center around the allowed volume fractions of flammable gases and the definition of the confinement barrier. Depending on interpretation, the regulations can become a severe constraint on TRU waste shipments, with no apparent benefit. In particular, the committee was unable to verify the technical basis for some of the interpretations of the regulations as they relate to the safety of the workers and the public. **The committee recommends a risk-informed analysis of WIPP specific shipment issues to identify core problems related to hydrogen generation and, perhaps, provide a basis for alternative cost-effective criteria while reducing the risk. The committee recommends the use of such risk-informed analysis in the application for revision of the USNRC certificate of compliance concerning hydrogen generation limits for transportation purposes.**

1

Introduction

The Waste Isolation Pilot Plant (WIPP) is the world's first deep underground operational geological repository for the disposal of radioactive waste. The WIPP consists of an underground mined facility located in a 250 million-year-old bedded salt formation (the Salado Formation), which lies 660 meters below the surface in a semiarid desert near the community of Carlsbad, New Mexico. The WIPP repository has been established for the disposal of transuranic (TRU) waste resulting from the nation's defense program. The advantages of the WIPP as a transuranic waste disposal are listed in Sidebar 1.1. Figures 1.1-1.3 show the location, layout, and geologic stratigraphy of the WIPP.

Transuranic waste contains alpha-emitting radionuclides that have atomic numbers greater than 92, the atomic number of uranium, the heaviest natural element. The WIPP Land Withdrawal Act (LWA) (U.S. Congress, 1992) defined TRU waste as waste contaminated with transuranic radionuclides with half-life[1] greater than 20 years and activity greater than 100 nanocuries per gram. It mainly consists of contaminated protective clothing, rags, old tools and equipment, pieces of dismantled buildings, chemical residues, and scrap material. Tables 1.1 and 1.2 provide, respectively, the inventory of major radionuclides in the WIPP and the repository inventory by waste category. More details on transuranic waste are given in Sidebar 1.2. Figure 1.4 shows pictures of typical TRU waste. Even though the backfill magnesium oxide (MgO) appears in the repository inventory, it is not considered to be waste. Water is also not part of the waste inventory. There is only a negligible amount of water in the waste, mostly water vapor and less than 1 volume percent of free liquids as allowed by the Waste Acceptance Criteria (DOE, 1999).

Packed in 55-gallon steel drums and wooden boxes, TRU waste is currently being stored at various sites across the nation. The source of the waste is the manufacture of nuclear warheads and the cleanup of the nuclear weapons sites. The risks associated with transuranic waste are related primarily to plutonium. Plutonium's long half-life (24,000 years for plutonium-239)[2] and toxicity must be considered in assess-

[1] The half-life is the time required for half of the atoms of a radioactive substance to disintegrate.

[2] Plutonium-239 indicates the isotope of mass number 239 of the element plutonium. The same notation is used for other radionuclides throughout this report.

Sidebar 1.1 Why the WIPP?

The rationale for isolating nuclear wastes through deep geologic disposal is based on a large body of U.S. and international research. The National Academy of Sciences observed in 1957 (NRC, 1957): "The best means of long-term disposal . . . is deep geological emplacement. . . ." The Academy reaffirmed and expanded on this view in NRC (1984) and in NRC (1996a). The WIPP repository is carved out of a bedded salt formation, with the following features that make it ideal for transuranic waste disposal:

Dry environment. Large salt beds are found only in geologic regions that lack significant flows of groundwater. This deep, relatively dry underground environment greatly reduces the possibility that wastes could be carried out of a repository by natural processes. The saltbed at the WIPP site has been stable for 225 million years. It can be expected, with high confidence, to remain that way for many thousands of years into the future.

Waste immobilization. Salt tends to "heal" itself after being mined because it gradually creeps under the pressure from overlying earth and fills any openings. After several hundred years, the salt at the WIPP is expected to close in on the waste and lock it deep below the surface.

Since the mid-1970s, the Department of Energy (DOE) and its scientific adviser, Sandia National Laboratories, have studied the WIPP site to make sure it is a safe place to isolate transuranic waste. The WIPP addresses the following two key national needs:

Reducing risk. As long as transuranic waste remains at storage sites, there will be some level of risk to populations near these sites. Also, workers who must maintain current sites and monitor wastes are frequently exposed to low levels of radiation.

Providing disposal. The WIPP is a first-of-its-kind deep geologic disposal facility and will provide a model for radioactive waste disposal. In addition to the existing inventory of stored transuranic waste, estimated at about 2.32 million cubic feet, the WIPP will be the disposal site for more than 3.7 million cubic feet of transuranic waste expected to be generated during the next 35 years as DOE sites are closed. Under current law, the DOE is allowed to store 6.2 million cubic feet of transuranic waste at the WIPP. SOURCE: Citizens' Guide to the Compliance Certification Application (DOE, 1996b).

SOURCE: Citizens' Guide to the Compliance Certification Application (DOE, 1996b).

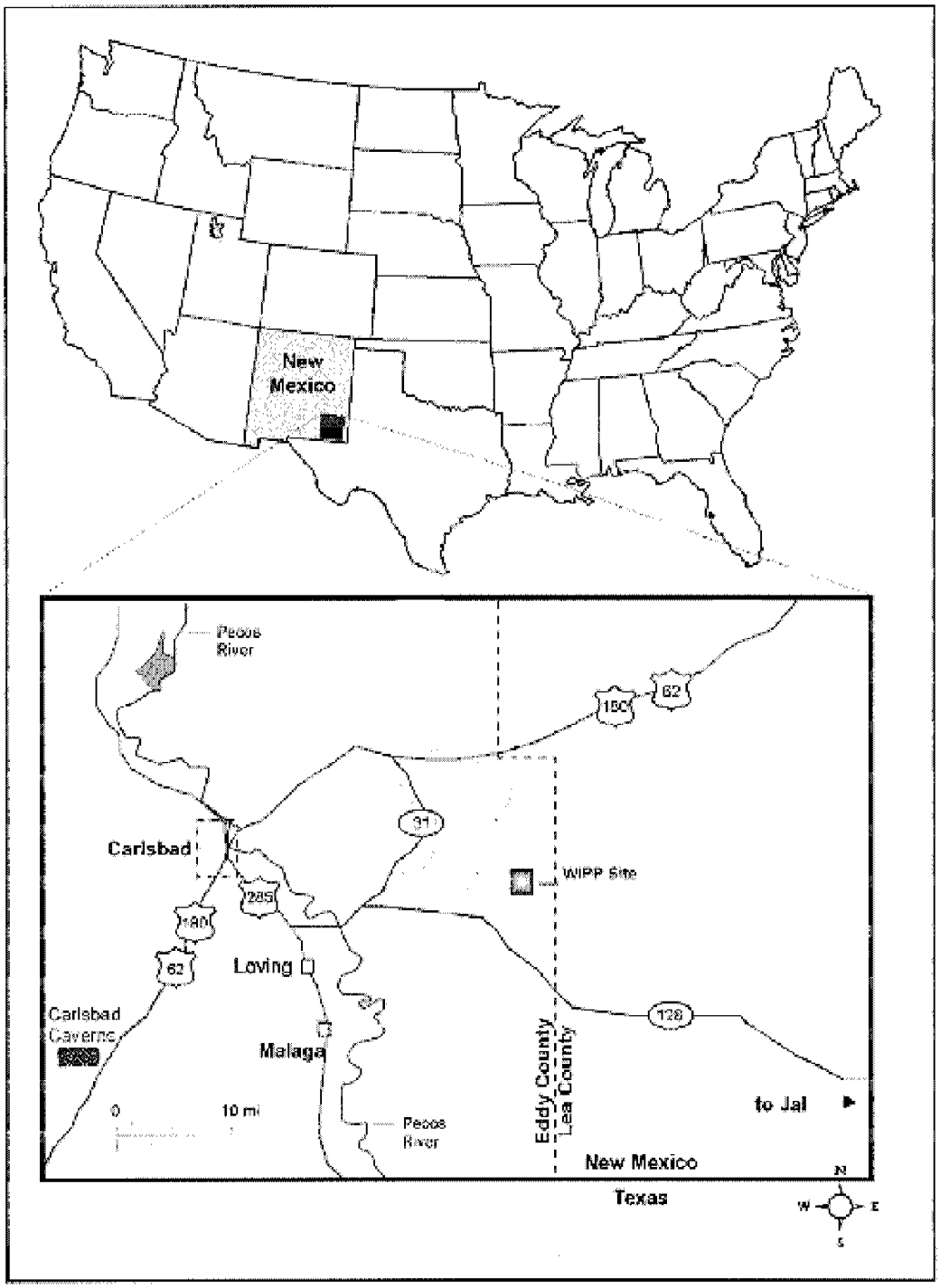


Figure 1.1 Location of the WIPP site. SOURCE: DOE, 2000g.

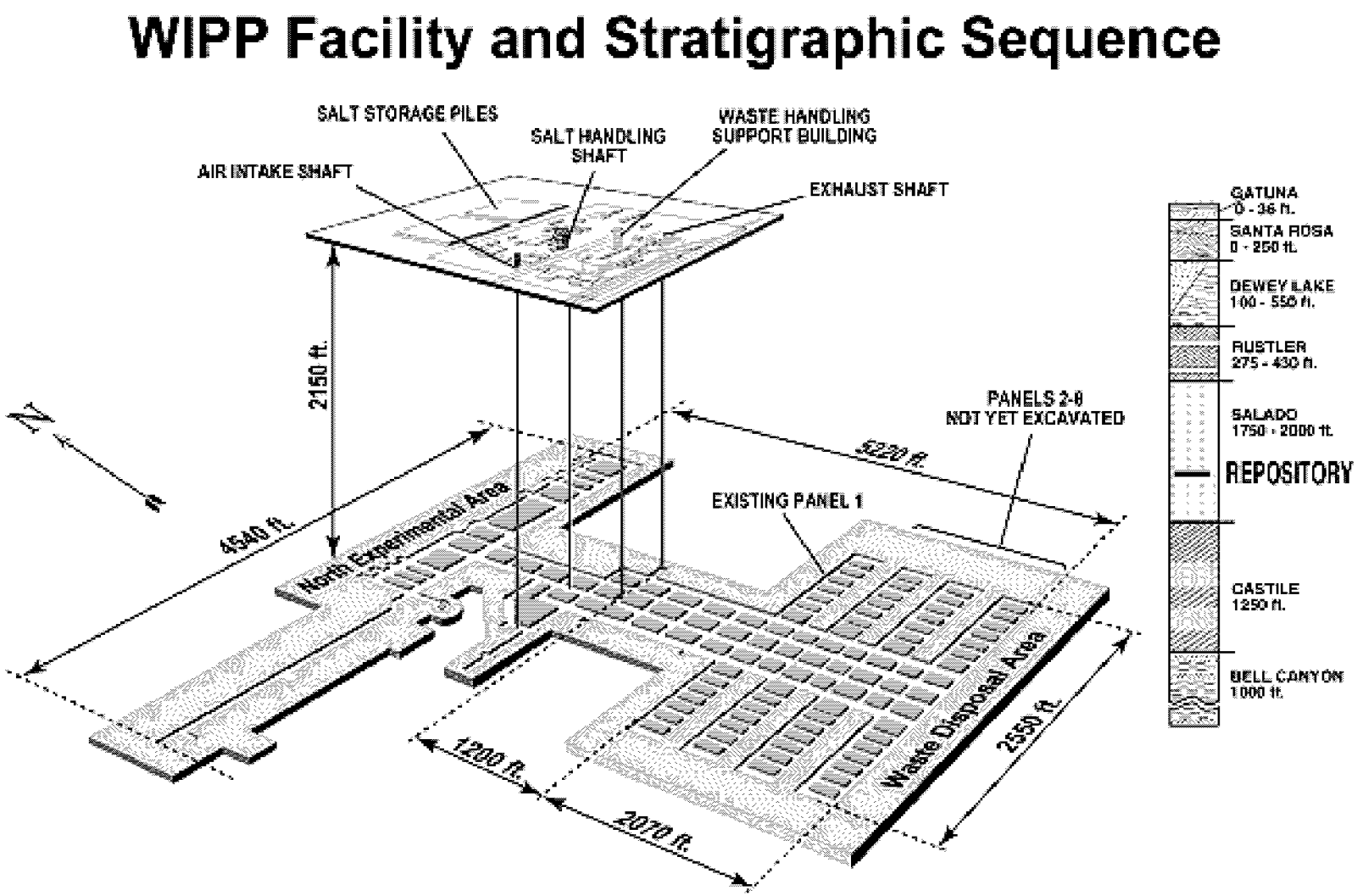


Figure 1.2 The WIPP facility and stratigraphic sequence. Panel 1 is currently in use. The mining of Panel 2 was completed on October 13, 2000. SOURCE: DOE, 2000h.

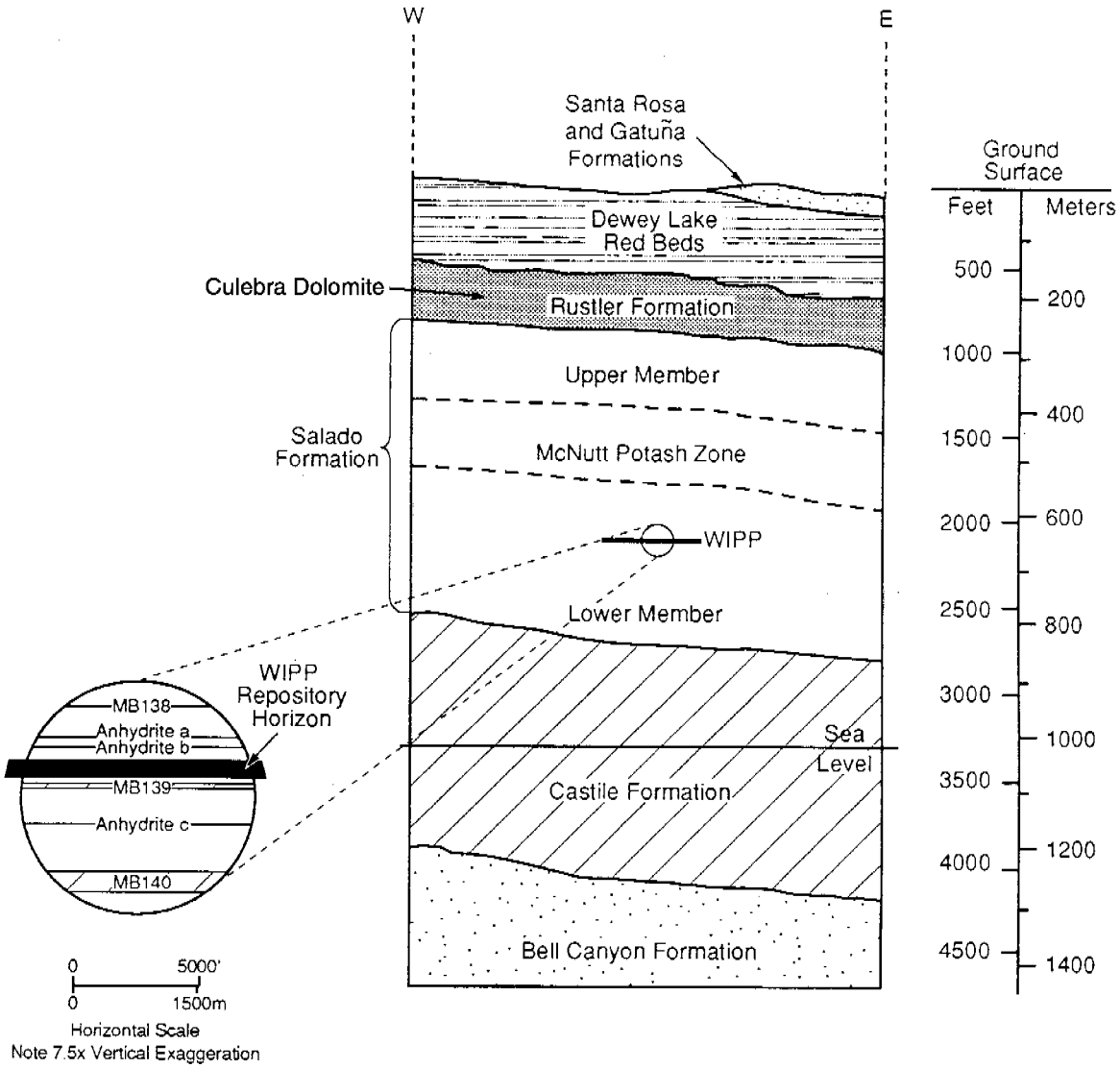


Figure 1.3 WIPP stratigraphy and depths of four key formations (Castile Formation, Salado Formation, Rustler Formation, and Dewey Lake Red Beds) including the position of the WIPP repository within the Salado. The Culebra Dolomite is one of the members of the Rustler Formation. It is approximately 7-8 meters thick at the WIPP site. Because it is a relatively transmissive unit, the Culebra is important to the groundwater flow model for the WIPP site. Inset shows finer-scale stratigraphy around the repository horizon, with marker beds and other thin beds. Adapted from Jensen et al. (1993).

Table 1.1 Inventory of the Most Abundant Radionuclides Expected in the Repository.[a]

Radionuclide	Contact Handled (CH)-Transuranic (TRU) Waste (Ci/m^3)	Remote Handled (RH)-Transuranic (TRU) Waste (Ci/m^3)
Am-241	2.62	0.842
Ba-137m	4.53×10^{-2}	28.9
Cm-244	0.187	4.45×10^{-2}
Co-60	3.83×10^{-4}	1.47
Cs-137	4.78×10^{-2}	30.5
Pu-238	15.5	0.205
Pu-239	4.66	1.45
Pu-240	1.25	0.715
Pu-241	13.7	20.0
Sr-90	4.07×10^{-2}	29.5
Y-90	4.07×10^{-2}	29.5

[a]The expected volumes of CH waste and RH waste are, respectively, 160,000 and 7,079 cubic meters.

SOURCE: DOE, 1996.

Table 1.2 Repository Inventory by Waste Category

Waste Category	Inventory (wt%)
Iron-based metal, alloys	14
Steel container material	12
Aluminum-based metal, alloys	1
Other metal, alloys	6
Other inorganic materials	3
Vitrified	5
Cellulosics	4
Rubber	1
Plastics	3
Plastic container or liner material	2
Solidified inorganic material (including cement)	4
Solidified organic material (not including cement)	0
Solidification cement	4
Soils	4
MgO backfill	37

SOURCE: Knowles et al., 2000.

ing not only the long-term risk of the WIPP, but also the potential radiation exposure of workers who handle, repackage, and transport the waste.

The WIPP has been under study since the mid-1970s, began construction in January 1981, was certified by the U.S. Environmental Protection Agency (EPA) in May 1998, and received its first transuranic waste shipment from the Los Alamos National Laboratory in March 1999. The first out-of-state shipment was received in June 1999 from the Rocky Flats Environmental Technology Site, and in September 2000, the first mixed-waste shipment was received from the Idaho National Engineering and Environmental Laboratory (INEEL). Figure 1.5 shows the main waste generators and the transportation routes to the WIPP.

Sidebar 1.2 What Is TRU Waste And How Is It Classified?

Transuranic waste is waste that contains alpha particle-emitting radionuclides with atomic numbers greater than that of uranium (92), half-lives greater than 20 years, and concentrations greater than 100 nanocuries per gram of waste. TRU waste is classified according to the radiation dose rate at package surface. As defined in the LWA, **contact-handled** (CH) TRU waste has a radiation dose rate at package surface not greater than 200 millirem per hour; this waste can safely be handled directly by personnel. **Remote-handled** (RH) TRU waste has a radiation dose rate at package surface of 200 millirem per hour or greater, but not more than 1,000 rem per hour (U.S. Congress, 1992); this waste must be handled remotely (i.e., with machinery designed to shield the handler from radiation). Alpha radiation is the primary factor in the radiation health hazard associated with TRU waste. Alpha radiation is not energetic enough to penetrate human skin but poses a health hazard if it is taken into the body (e.g., inhaled or ingested). In addition to alpha radiation, TRU waste also emits gamma and/or beta radiation, which can penetrate the human body and requires shielding during transport and handling. RH TRU waste has gamma and/or beta radiation-emitting radionuclides in greater quantities than exist in CH TRU waste (DOE, 2000a).

TRU waste is further classified as TRU waste or **mixed** TRU waste. Mixed TRU waste contains both radioactive materials regulated under the Atomic Energy Act and hazardous chemical compounds regulated under the Resource Conservation and Recovery Act.

The total activity of the waste expected to be disposed at the WIPP is estimated to be approximately 7 million curies (of which 6 million is from CH waste), including 12,900 kilograms of plutonium distributed throughout the waste in very dilute form. According to the Compliance Certification Application (CCA), the volume of CH waste expected in WIPP is 160,000 cubic meters and that of RH waste is 7,079 cubic meters (DOE, 1996).

The WIPP is designed to dispose of approximately 175,000 cubic meters of transuranic waste. Total activity of the waste is estimated to be approximately 7 million curies. The largest fraction of this activity comes from approximately 12,900 kilograms of plutonium distributed throughout the waste in very dilute form. TRU waste is classified as contact-handled (CH) and remote-handled (RH) waste, according to the radioactivity at the container surface [3] (see Sidebar 1.2). According to the National TRU Waste Management Plan, the disposal of RH waste will not begin before early 2002 (DOE, 2000a). Since most of the radioactivity is coming from the plutonium in CH waste (approximately 85 percent of the total curies inventory, see Table 1.1), the disposal of RH waste should not represent a significant added risk to the repository. A further issue concerning RH waste will be discussed in relation with the emplacement of backfill in Chapter 2.

This report presents the results of a National Research Council (NRC) study of operational, technical, and programmatic issues associated with the long-term performance of the WIPP. Previous studies

[3] This type of classification is intended for the protection of workers handling radioactive waste. Public health protection standards have also been taken into account in the design and operation of the WIPP.

Figure 1.4 Radiography of a transuranic waste drum. SOURCE: DOE, 2000i.

by the NRC's committee on the WIPP covered ongoing activities in preparation for the opening of the facility. This study is the first to address the WIPP as an operational repository.

The seeds for this report were planted during the preparation of the 1996 report by the previous WIPP committee (NRC, 1996a). That committee observed that the long operating period of the WIPP (at least 35 years and possibly much longer) provides an opportunity to conduct studies and investigations that would decrease some of the uncertainties about the long-term safety performance of the repository.

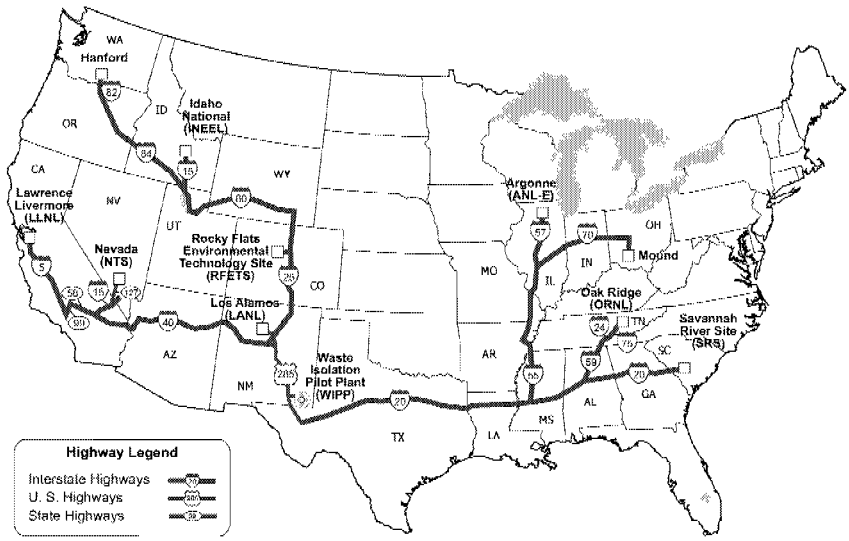


Figure 1.5 Defense transuranic waste generating and storage sites and primary transportation routes. SOURCE: DOE, 2000j.

Thus, this committee has focused on identifying studies and investigations "that would enhance the assessment of long-term repository performance," as noted in the statement of task in the Preface to this report. The second part of this committee's statement of task addresses potential improvements to the National Transuranic Waste Management Plan, also known as the National TRU Program. This program coordinates the management and disposal activities of TRU waste between the WIPP and the 23 generator sites. As written in the statement of task, the committee must "identify areas for improvement in the TRU waste management system that may increase system throughput, efficiency, cost-effectiveness, or safety to workers and the public." The result is the consideration of issues having to do with waste characterization, packaging requirements, waste transportation and handling, and emergency preparedness.

The two-part statement of task required very different skills and approaches: the first part is related to site performance, while the second is programmatic. The committee has chosen to structure this report into two primary sections that can be mapped directly to the two principal requirements of the statement of task. The part of the statement of task relevant to the long-term performance of the repository is addressed in the context of the repository performance confirmation program, in reference to enhancing confidence in the performance assessment models. The task relating to programmatic issues is addressed in the context of the National TRU Program.

SITE PERFORMANCE AND CHARACTERIZATION

To evaluate the long-term performance of the disposal system, the DOE uses a technique developed especially for predicting the behavior of geologic repositories over the thousands of years required for waste isolation. This technique is called "performance assessment." Performance assessment (PA) is a multidisciplinary, iterative, analytical process that begins by using available information that characterizes the waste and the disposal system (the design of the repository, the repository seals, and the natural barriers provided by the host rock and the surrounding formations). To obtain certification for the WIPP,

the DOE used the PA tool to estimate the releases of radionuclides within the first 10,000 years, based on the probabilities of relevant features, events, and processes occurring.

The performance of the repository has been assessed for two main scenarios: the undisturbed repository scenario and the human intrusion scenario. If the repository is left undisturbed, the only release pathway for radionuclide release into the environment is through leakage of brines containing radioactive materials into the environment. Scenarios for the disturbed case involve releases resulting from boreholes drilled inadvertently into the waste. According to the Land Withdrawal Act (U.S. Congress, 1992), the DOE must exercise active institutional controls[4] on a perimeter of land extending up to 5 kilometers from the boundaries of the WIPP site for 100 years after the closure of the repository. During this period, there will be no natural resource extraction activities in the site. Between 100 and 700 years after the closure of the repository, the site will be under passive institutional controls.[5] During this period, drilling activity is expected to resume and to reach its maximum after 700 years, when the land will be released to public use and the WIPP site will be no longer controlled. Uncontrolled extraction activities would increase the probability of drilling directly into the repository.

Sensitivity analyses are used by the DOE to determine which parameters of the disposal system exert the greatest effect on performance (DOE, 1996). Performance assessment calculations show that in the absence of human intrusion, brine inflow and gas generation are the most important parameters affecting the performance of the WIPP (Helton, 2000d). In the case of the disturbed scenario, the most important parameter is the borehole permeability (Helton, 2000e). Sidebar 1.3 describes the main results of the performance assessment and their implication for the long-term performance of the WIPP. For a complete review of the PA for the WIPP see Apostolakis et al. (2000). The containment requirements are set by the regulatory agency, the U.S. Environmental Protection Agency, and are listed in Sidebar 1.4. More information on regulatory compliance can be found in the previous NRC report on the WIPP (NRC, 1996a).

The EPA certified the WIPP on the basis of the performance assessment included in the Compliance Certification Application (CCA). While various mechanisms and scenarios, including their uncertainties, were considered in the performance assessment, the question now is how to enhance the degree of confidence expressed by the performance assessment results. The conceptual structure and the development of scenarios for the WIPP's PA are described respectively in reference Helton et al. (2000a) and Galson et al. (2000).

The uncertainties in the PA for the WIPP are analyzed in Helton et al. (2000b,c). The current committee on the WIPP believes that better knowledge of site performance and better site characterization are important in decreasing the uncertainties, and therefore possibly enhancing the confidence, in the performance assessment of the repository. The committee's approach to examining the PA was to focus on underlying assumptions and results of the performance assessment. Of particular interest to the committee was how the results could be impacted by uncertainties and relied upon EPA's certification for proof of the ability of the computer program to represent the model adequately. The issues and their uncertainties are discussed in Chapter 2 as site performance and site characterization issues.

THE NATIONAL TRANSURANIC PROGRAM

The National Transuranic Waste Management Plan, also known as the National TRU Program, is a plan that organizes the activities concerning storage, characterization, packaging, handling, transporta-

[4] Active institutional controls imply restrictions on land access or use.

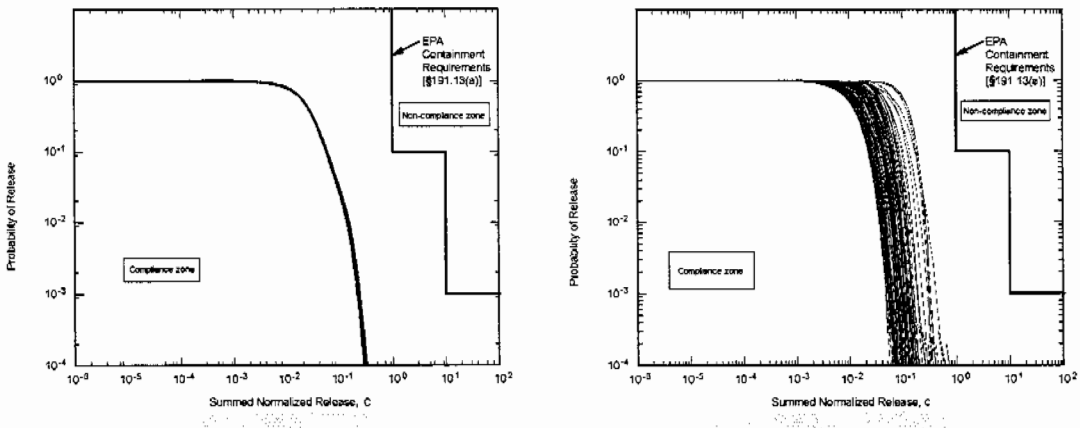
[5] Passive institutional controls imply the identification of the controlled area through signs or markers; also, records are kept on the repository and land use.

Sidebar 1.3 Performance Assessment and Regulatory Acceptance

The Environmental Protection Agency's certification of the WIPP facility was based on the performance assessment submitted as a part of the U.S. Department of Energy's Compliance Certification Application. The regulatory basis for the PA for the WIPP is described in Howard et al. (2000). The PA is a computerized, mathematical model that evaluates the performance of the WIPP repository over its lifetime. The main results of this model are shown in Figure A below, and are compared there with the acceptance criterion established by the EPA shown as the line in the upper right corner. These requirements are reported in Sidebar 1.4. The horizontal axis is a measure *C*, of the total radioactivity released from the repository to the biosphere during its nominal 10,000-year lifetime. The vertical axis shows the "probability of release," that is, at any value of *C*, the probability that the actual release from the repository will exceed that value. Such a curve is called a "complementary cumulative distribution function (CCDF)." It expresses quantitatively the state of knowledge of the analysis team about how much radioactivity will be released from the repository over its lifetime. It is important to observe that the curve is well to the left of the regulatory acceptance boundary set by the EPA, meaning that the repository is in compliance with the regulation.

A variation on this form of presentation is shown in Figure B. In this figure, a family of CCDFs is traced to show the different effects of uncertainties arising from possible human intrusions into the repository (mainly by drilling into it) and the geotechnical uncertainties (e.g., physical and chemical properties of the salt). Again, the important result is that the whole family of curves is well to the left of the EPA acceptance boundary. In addition, the curves bunched close together indicate a reasonable bound on the uncertainties and add confidence that a substantial margin of safety exists.

continued



Figures A (*left*) **and B** (*right*) Complementary cumulative distribution functions resulting from the performance assessment. In A, the probability of radionuclide release from the repository is compared to the acceptance criteria. In B, a family of CCDF curves is traced to show the effect of different uncertainties. The "summed normalized release" of radionuclides C, is related to WIPP containment requirements in Sidebar 1.4. The term "normalized" release means that the release *Cj* is divided by the release limit *Lj*. The use of the term "summed" indicates the sum of all *Cj/Lj* over all the radionuclides with half-life greater than 20 years. The summed normalized release represents the total radioactivity released from the repository to the biosphere during its nominal 10,000-year lifetime. More details on CCDFs can be found in NRC (1996a). SOURCE: DOE, 2000k.

Sidebar 1.3 Continued

The committee recognizes that computing the performance of an underground repository over many millennia into the future cannot be done today with the accuracy with which, for example, the performance of an airplane wing can be simulated. Nevertheless, the results of this performance assessment are considered adequate by experts and regulators to support the decision to move waste from its surface storage to the WIPP (EPA, 1998).

Sidebar 1.4 Containment Requirements

Title 40 CFR 191.13 requires that "disposal systems for . . . transuranic radioactive wastes shall be designed to provide a reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

1. Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 . . .; and
2. Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1. . .".

To explain how these requirements are applied to the WIPP, let L_j be the limit shown in the above table for radionuclide *j*. Suppose for the moment that WIPP had only one radionuclide, *j*, and let C_j be the total release of that radionuclide to the environment, measured in curies per 1000 metric tons of heavy metal (MTHM), during its 10,000 year lifetime. Then the first requirement of 40 CFR 191.13 means that the probability of C_j being greater than L_j should be less than 0.1.

That is: $p(C_j/L_j > 1)$ should be < 0.1

The second requirement then indicates that

$p(C_j/L_j > 10)$ should be < 0.001.

The actual inventory of radionuclides *C*, is defined as:

$$C = \sum_{j}^{N_j} \frac{C_j}{L_j}$$

with N_j being the total number of radionuclides with a half-life greater than 20 years.
The requirements then become:

$p(C>1)$ should be < 0.1
$p(C>10)$ should be < 0.001

Table 1. Release Limits per 1,000,000 Curies of TRU Waste per 10,000 Years[a]

Radionuclide	Release Limit (curies per 1000 MTHM)
Americium-241 or 243	100
Carbon-14	100
Cesium-137 or 137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, 239, 240, or 242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or 232	10
Tin-126	1,000
Uranium-233, 234, 235, 236, or 238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life grater than 20 years that does not emit alpha particles	1,000

[a] Containment requirements for selected isotopes as declared in Title 40 CFR 191, Appendix A (EPA, 1995). The release limits specified here scale with the quantity of waste in a repository; for this reason, they are specified in terms of curies that may be released per 10,000 years per 1,000 metric tons of heavy metal (MTHM). For a repository such as WIPP, which is intended to contain transuranic wastes, EPA has established in 40 CFR 191 that 1,000 MTHM is equivalent to 1,000,000 curies of TRU wastes with greater than 20-year half-lives. Therefore, the limits specified are applicable per million curies of TRU waste.

tion, and disposal of defense-related transuranic waste to the WIPP from the 23 generator sites. The National TRU Program is administered by the DOE's Carlsbad Field Office. The goals of the National TRU Program are the following:

- achieving regulatory compliance among all the sites,
- reducing risk while maximizing rate of TRU waste disposal,
- reducing mortgage costs by closing the generators' sites as soon as possible, and
- using the WIPP effectively by coordinating the shipments with the repository's waste-handling and disposal capabilities.

The issues considered in this report relate primarily to waste characterization and packaging and waste transportation. Because of their importance in the near term for achieving the beginning of operation at the WIPP, the committee focused on these issues in its interim report, reported in Appendix A1. In Chapter 3 of this final report, the committee re-visits the issues related to characterization, packaging, and transportation of the wastes, including communication systems and emergency preparedness. The issue of hydrogen gas generation, as it applies to both waste characterization and transportation, is also discussed in Chapter 3.