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DOE/WIPP 89 - 011
Revision 1

Test Phase Plan for the Waste Isolation Pilot Plant

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United States Department of Energy
WIPP Project Integration Office
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PREFACE

The U.S. Department of Energy (DOE) has prepared this plan to describe and guide the test phase for the Waste Isolation Pilot Plant (WIPP), a mined, geologic repository developed in southeastern New Mexico to demonstrate the safe, permanent disposal of radioactive transuranic (TRU) wastes generated in defense activities. The test phase encompasses a program of analyses of the performance of the planned repository based on scientific studies, including tests with transuranic mixed waste, directed at evaluating compliance with the principal regulations governing the WIPP.

A plan for the test phase is required by the WIPP Legislative Land Withdrawal Act (LWA) (Public Law 102-579). The DOE is required to submit a test phase plan and a waste retrieval plan to the U.S. Environmental Protection Agency (EPA) for review, giving notice in the *Federal Register* that the plans have been submitted, and providing opportunity for public access to the plans. The regulatory scope of this *Test Phase Plan for the Waste Isolation Pilot Plant* is limited to the key regulations governing the WIPP: the environmental standards for the disposal of transuranic waste (40 CFR Part 191, except Subpart A) and the pertinent regulations implementing the Solid Waste Disposal Act (SWDA) (42 U.S.C. 6901, *et. seq.*) as amended by the Resource Conservation and Recovery Act (RCRA) and subsequent amendments to the RCRA (40 CFR 264, Subpart X and 40 CFR 268.6). These regulations have been promulgated by the EPA, which is also responsible for certifying the DOE's demonstration of compliance with the final disposal regulations. In a single rulemaking procedure, the EPA is to determine whether to approve, in whole or in part, or disapprove the *Test Phase Plan for the Waste Isolation Pilot Plant* and whether to approve or disapprove the waste retrieval plan.

The EPA is to approve this Plan if the agency determines that the activities described are directly relevant to a certification of compliance with the final disposal regulations (40 CFR 191, Subparts B and C) or to compliance with the SWDA (as amended by the RCRA, 42 U.S.C. 6901, *et. seq.*). If the Plan or any portion of it is not approved, the DOE may submit a revised Plan; the DOE may also submit modifications; however, either revisions or modifications require the EPA's approval by rulemaking. Tests with transuranic waste in the WIPP underground will not be started until conditions set forth in section 6 of the LWA are met, including EPA approval of this Plan.

This *Test Phase Plan for the Waste Isolation Pilot Plant* is based on the DOE's current understanding of the pertinent regulations and specific requirements in the LWA. The latter specifies that the Plan is to (1) set forth the test-phase activities to be conducted at the WIPP, (2) specify the quantities and types of transuranic waste required for such activities, (3) describe how the activities are designed to provide information directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA (as amended by the RCRA, 42 U.S.C. 6901, *et. seq.*), and (4) justify all those activities. This Plan reflects the agreements that the DOE has entered into with the State of New Mexico; comments made by the National Academy of Sciences on earlier plans for the test program; programmatic considerations pertinent to the WIPP program in particular and the management of transuranic wastes in general; and various technical documents, which are cited here as appropriate.

Other environmental laws and regulations with which the DOE must comply are not addressed in this Plan. These include the environmental standards for the management and storage of transuranic waste (40 CFR Part 191, Subpart A), the National Environmental Policy Act, the Clean Air Act, the Safe Drinking Water Act, the Toxic Substances Control Act, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and all other applicable Federal laws, regulations, and

permit requirements. Compliance with these is demonstrated separately. The DOE is required by the LWA to document continued compliance with these laws and regulations every two years.
The Plan begins with background information on the WIPP Project and the requirements of the LWA that establish its objective and scope (Chapter 1). It then presents an overview of the regulatory requirements and the compliance approach (Chapter 2). Comprehensive discussions of plans for compliance with the disposal regulations (Chapter 3) and the SWDA (as amended by the RCRA, 42 U.S.C. 6901, *et. seq.*) (Chapter 4) and descriptions of activity programs designed to provide information needed for determining compliance are the nucleus of this Plan. Chapter 5 contains descriptions and justifications of all currently planned studies that are designed to support these activities.

The activity programs and supporting studies described in this Plan are the DOE's best current estimate of the research, development, and design work that will provide the information directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA (as amended by the RCRA, 42 U.S.C. 6901, *et. seq.*). The LWA reinstated 40 CFR 191 Subpart B for WIPP as issued on September 19, 1985, except for the remanded aspects of sections 191.15 and 191.16. On February 10, 1993 the EPA proposed final disposal regulations for WIPP. The EPA has not yet established criteria for certification of compliance with the final disposal regulations as required by the LWA. As the certification criteria are developed by the EPA and understood by the DOE, additional studies may be proposed to provide data required for demonstrating compliance with the final disposal regulations. Similarly, the EPA may, in the process of evaluating applications relevant to the SWDA (as amended by the RCRA, 42 U.S.C. 6901, *et.seq.*), identify additional data that are needed to demonstrate compliance. However, the DOE believes that the currently planned activities are broad enough in scope to support demonstration of compliance with each of these regulations, as they are currently understood. The DOE will review the program in light of the final disposal regulations and the associated certification criteria, when they are available. If during conduct of the test phase, the DOE should ascertain that the necessary information can be obtained without performing all the studies described here, or that additional information is required that can be obtained under existing activities, the scope of the test phase will evolve appropriately. A formal modification to this Plan will be submitted to the EPA if new activities are proposed that are outside the objectives of the activities described here or that change the quantities and types of transuranic wastes or transuranic mixed wastes discussed in this *Test Phase Plan for the Waste Isolation Pilot Plant*.

The DOE is no longer characterizing the in situ tests at the WIPP with transuranic waste as necessary to demonstrating compliance. However, the DOE believes these tests, along with the other studies described in this Plan, will provide data that are "directly relevant" to compliance, consistent with the LWA. At the same time, to assure that appropriate contingency plans are in place if the EPA disapproves some or all of the waste tests, the DOE will evaluate alternative experimental methods that may or may not involve waste and that could yield equivalent data. The currently planned waste tests at the WIPP, as described in this Plan, involve a nominal 0.13 percent of the waste capacity limitation set by the LWA. This amount is about one-quarter the amount identified in the 1990 Test Phase Plan.

The Plan is sufficiently detailed to describe the DOE's approach to the demonstration of compliance; it is directed at summarizing the relevance to compliance for the test-phase activities rather than describing details of experiments. Such details will be found in the test plans developed for individual studies. Readers interested in a comprehensive treatment of the scientific basis for test-phase studies that involve TRU mixed wastes, which are designed to provide information on gas generation and on the actinide source term, are referred to the *Gas Generation and Disposal Room Source-Term Program: Technical Needs Assessment for the WIPP Test Phase* (DOE, 1992a).

A previous version of this Plan, Revision 0, was issued in April 1990 (DOE, 1990d) following EPA, NAS, EEG, and State of New Mexico review and comment. Revision 0 was reviewed by the EPA during the process that led to the granting of the conditional no migration determination for the WIPP test phase in November of 1990 (EPA, 1990a). Revision 1 is an update that further addresses compliance with the LWA and documents changes in the test program since April 1990. A summary of the differences between the two revisions is contained in Appendix A.

Section 8 (f) of the LWA requires periodic recertification of compliance with the regulatory requirements, after the disposal decision is made. Some aspects of activities described in this plan could be continued beyond the test phase if they would provide information relevant to the periodic recertifications of compliance or if they would provide confirmatory information. These might include tests involving TRU mixed waste and tests that do not involve TRU mixed waste.

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ACRONYMS AND INITIALISMS

CAMCON	Compliance Assessment Methodology Controller
CCDF	Complementary Cumulative Distribution Function
CDF	Cumulative Distributions Function
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH	Contact Handled
DOE	Department of Energy
DRZ	Disturbed Rock Zone
EATF	Engineered Alternatives Task Force
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FSEIS	Final Supplement: Environmental Impact Statement
GGP	Gas Generation Program
HSWA	Hazardous and Solid Waste Amendments
INTRAVAL	International Project to Study Validation of Geosphere Transport Models
LWA	Land Withdrawal Act
MB	Marker Bed
MPa	MegaPascal
NAS	National Academy of Sciences
NMD	No-Migration Determination
NMED	New Mexico Environment Department
NMVP	No Migration Variance Petition
NRC	Nuclear Regulatory Commission
RCRA	Resource Conservation and Recovery Act
RH	Remote Handled
SEIS	Supplemental Environmental Impact Statement
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
SWDA	Solid Waste Disposal Act
TDS	Total Dissolved Solids
TNAD	Technical Needs Assessment Document
TRU	Transuranic
TSI	Thermal/Structural Interactions
VOC	Volatile Organic Compound
WAP	Waste Analysis Plan
WCPP	Waste Characterization Program Plan
WIPP	Waste Isolation Pilot Plant

Executive Summary

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) has prepared this *Test Phase Plan for the Waste Isolation Pilot Plant* to satisfy the requirements of Public Law 102-579, t[redacted] Land Withdrawal Act (LWA). The Act provides seven months after its enactment for the DOE to submit this Plan to the Environmental Protection Agency (EPA) for review.

A potential geologic repository for transuranic wastes, including transuranic mixed wastes, generated in national-defense activities, the WIPP is being constructed in southeastern New Mexico. Because these wastes remain radioactive and chemically hazardous for a very long time, the WIPP must provide safe disposal for thousands of years. The DOE is developing the facility in phases. Surface facilities for receiving waste have been built and considerable underground excavations (2150 feet below the surface) that are appropriate for in-situ testing, have been completed. Additional excavations will be completed when they are required for waste disposal.

The next step is to conduct a test phase. The purpose of the test phase is to develop pertinent information and assess whether the disposal of transuranic waste and transuranic mixed waste in the planned WIPP repository can be conducted in compliance with the environmental standards for disposal and with the Solid Waste Disposal Act (SWDA) (as amended by RCRA, 42 U.S.C. 6901 *et. seq.*). The test phase includes laboratory experiments and underground tests using contact-handled transuranic waste. Waste-related tests at WIPP will be limited to contact-handled transuranic and simulated wastes since the LWA prohibits the transport to or emplacement of remote-handled transuranic waste at WIPP during the test phase.

The LWA identifies the objective of this Plan: to show that the test phase is designed to provide data that are directly relevant to a certification of compliance with the final disposal regulations of 40 CFR 191 (Subparts B and C) or to compliance with the SWDA (as amended by RCRA, 42 U.S.C. 6901 *et. seq.*). The activity programs and supporting studies described in this Plan are the DOE's best current estimate of the research, development, and design work that will provide the information directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA (as amended by RCRA, 42 U.S.C. 6901 *et. seq.*). The LWA reinstated 40 CFR 191, Subpart B for WIPP as issued on September 19, 1985, except for the remanded aspects of sections 191.15 and 191.16. On February 10, 1993 the EPA proposed final disposal regulations for WIPP. The EPA has not yet established criteria for certification of compliance with the final disposal regulations as required by the LWA. As the certification criteria are developed by the EPA additional studies may be proposed to provide data necessary for demonstrating compliance with the final disposal regulations. Similarly, the EPA may, in the process of evaluating applications relevant to RCRA, identify additional data that are needed to demonstrate compliance. However, the DOE believes that the currently planned activities are broad enough in scope to support demonstration of compliance with each of these regulations, as they are currently understood. The DOE will review the program in light of the final disposal regulations and the associated certification criteria, when they are available. If during conduct of the test phase, the DOE should ascertain that the necessary information can be obtained without performing all the studies described here, or that additional information is required that can be obtained under existing activities, the scope of the test phase will evolve appropriately. A formal modification to this Plan will be submitted to the EPA if new activities are proposed that are outside the objectives of current activities (listed below) or that change the quantities and types of transuranic wastes or transuranic mixed wastes discussed in this *Test Phase Plan for the Waste Isolation Pilot Plant*.

According to the LWA, the Plan must (1) set forth the test phase activities to be conducted at WIPP, (2) specify the quantities and types of transuranic waste required for such activities, (3) describe how the activities are designed to provide information directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA (as amended by RCRA, 42 U.S.C. 6901 *et. seq.*), and (4) justify all such activities. This Plan reflects agreements that the DOE has entered into with the State of New Mexico; the comments made by the National Academy of Sciences on previous test phase plans; programmatic considerations pertinent to the WIPP program and management of transuranic wastes; and input from various technical documents, which are cited in this Plan as appropriate.

This Plan describes DOE plans for demonstrating compliance with both long- and short-term regulations that apply to the WIPP. For the demonstrations of compliance for the long term, as required by 40 CFR Part 191 and 40 CFR 268.6, the DOE will use performance assessment to predict the behavior of the WIPP over thousands of years. Performance assessment is an analytical process that begins by using available information to characterize the waste and the disposal system. This assessment evaluates the natural barriers provided by the host rock and the surrounding formations and the design of the repository and the engineered barriers. The assessment identifies the processes (i.e., phenomena that might develop slowly, over long periods of time) and events that might affect the system. It examines the effects of these processes and events on the performance of the overall system. Release estimates of radionuclides and hazardous chemical constituents can then be developed, considering associated uncertainties, and sensitivity analyses can be performed to determine which characteristics of the disposal system or which processes or events exert the greatest effect on system performance.

Approaches to evaluating compliance for the long term under 40 CFR Part 191 and 40 CFR 268.6 will be similar. For the 40 CFR Part 191 evaluation, the performance assessment will focus on the behavior of radionuclides. For the long-term 40 CFR 268.6 evaluation, the performance assessment will focus on the behavior of hazardous chemical constituents. Performance-assessment modeling and analysis will provide a quantitative evaluation of long-term isolation and containment of radionuclides and hazardous constituents. Information necessary to simulate performance must adequately represent the disposal system, composed of the natural barriers and the repository with its engineered barriers, as well as the interactions of the waste with the disposal system.

Developing an information base from which appropriate conceptual models and parameter values can be derived for the performance assessment is the principal reason for conducting the test phase; this information base will also help evaluate the uncertainties associated with the performance assessments completed to date. Other reasons are to develop detailed designs, to conduct in-situ demonstrations of seal emplacement technology and initial seal performance, and to establish that shaft, drift, panel, and borehole seals will meet the required design/performance criteria. In addition to its primary objective of demonstrating regulatory compliance, the performance assessment provides guidance to the experimental and testing programs by helping to identify additional information needs, to set priorities for obtaining additional data, and to evaluate the adequacy of available information. The preliminary performance assessments provide estimates of the effectiveness of the design of the planned repository. If a reasonable expectation of compliance cannot be demonstrated for the WIPP as it is currently designed, engineered alternatives may be considered for improving performance.

To demonstrate compliance with 40 CFR 268.6 during the short term (i.e., test phase, disposal phase, and decommissioning phase), the DOE will evaluate whether the WIPP will satisfy the no-migration standard. This demonstration of compliance will be accomplished by assessing the movement of hazardous chemical constituents in the underground ventilation air stream during the disposal and decommissioning phases and by comparing the predicted concentrations of hazardous constituents with

EPA-approved health-based levels. In addition, analyses must be performed to demonstrate that the migration of hazardous constituents in concentrations exceeding health-based levels through other pathways is not likely to occur during these phases of the project.

The DOE must also demonstrate that the WIPP will meet the environmental performance standard of 40 CFR 264, Subpart X during the short term. While this evaluation will be similar to that for the short-term no-migration evaluation, the potential for human and environmental risks will be evaluated based either on numerical health and environmental standards or on non-numerical performance requirements necessary to protect human health and the environment. The DOE will analyze the potential human health and environmental impacts of the management of transuranic mixed waste at the WIPP facility. This analysis—performed by evaluating the quantities and concentrations of hazardous constituents available for release from the waste, the potential pathways for release, the potential receptors, and the human health and environmental consequences of any releases—will require data, which can be obtained from studies planned during the test phase, including those using transuranic mixed waste. This analysis will address the air, soil, ground-water, and surface water pathways.

The test phase program has been designed by the DOE to ensure that information needed to evaluate compliance is available to the performance assessment and for waste mobility modeling efforts and the assessment of environmental risks. The general structure for compliance is (1) identification of the applicable regulatory requirements, (2) development of a compliance approach, (3) identification of information needed for assessing regulatory compliance, and (4) completion of activities that will satisfy the information needs.

Information needs for demonstrating compliance are categorized by the parts of the disposal system (natural barriers or repository design and engineered barriers), by the effects of the wastes (waste interactions), or by significant events affecting the disposal system (human intrusion). Activities have been designed to provide the needed information about various subsystems or components of these categories. These activities are presented as integrated programs each comprising several studies of the phenomena contributing to the performance of the particular subsystem or component, or the response of the disposal system to an event.

Activities to be performed during the test phase to satisfy the information needs for evaluating compliance with the regulations are:

- 40 CFR Part 191 (Long-Term Performance)

  Natural Barriers: Non-Salado Hydrologic Properties; Non-Salado Transport; Salado Hydrology; Salado Transport; Site Characteristics.

  Repository Design and Engineered Barriers: Disposal Room Performance; Shaft, Drift, and Borehole Seals Performance; Shaft, Drift, and Borehole Seals Designs; Disturbed Rock Zone Permeability; Shaft, Drift and Borehole Closure; Repository Design.

  Waste Interactions: Gas Generation Characteristics; Radionuclide Source Term in Disposal Room Brine; Waste Characterization.

  Human Intrusion: Human Intrusion Modeling; Probability of Human Intrusion; Cuttings Release Parameters.

- 40 CFR 268.6 (Long-Term Performance)

  Natural Barriers: Salado Hydrology; Salado Transport; Site Characteristics.

  Repository Design and Engineered Barriers: Disposal Room Performance; Shaft, Drift, and Borehole Seals Performance; Shaft, Drift, and Borehole Seals Designs; Disturbed Rock Zone Permeability; Shaft, Drift and Borehole Closure; Repository Design.

  Waste Interactions: RCRA Constituents Source Term in Disposal Room Brine and Gas; Gas Generation Characteristics; Waste Characterization.

- 40 CFR 268.6 and 40 CFR 264, Subpart X (Short-Term Performance)

  Natural Barriers: Site Characteristics.

  Repository Design and Engineered Barriers: Disposal Room Performance; Shaft, Drift, and Borehole Seals Performance; Shaft, Drift, and Borehole Seals Designs; Disturbed Rock Zone permeability, Shaft, Drift and Borehole Closure; Repository Design.

  Waste Interactions: Gas Generation Characteristics, Waste Characterization.

To address the information needs listed above, DOE will perform numerous studies. These studies will include laboratory and field tests and modeling exercises. In many cases, these are ongoing studies that have been underway for a number of years. Studies that do not require testing with transuranic and simulated wastes will be conducted to provide necessary information about the disposal system. Information will be developed about waste interactions that are independent of the radioactive or hazardous nature of these wastes. Additional studies will be conducted to assess the probability of human intrusion and to determine the potential effects of human intrusion.

By authorizing the EPA to determine, in a rulemaking procedure, whether the information provided by the test phase activities is directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA (as amended by RCRA, 42 U.S.C. 6901 *et. seq.*) the LWA authorized EPA to evaluate the relevance of the information. As defined by DOE, information gathered through test phase activities is relevant to a certification of compliance with 40 CFR Part 191, or to compliance with 40 CFR 268.6 and 40 CFR 264 Subpart X, if it meets either of the following conditions:

- Information is relevant if it is pertinent to developing an understanding of or to predicting effects of parameters, processes, and events important to the assessment of and determination of compliance with the regulatory requirements. Parameters, processes, and events include the design basis performance of the facility and disposal system, waste characterization, waste interactions, and human intrusion or predictable future events.

- Information is relevant if it improves the confidence in a technical description (conceptual model) of a parameter, process or event and its representation in compliance assessments.

The DOE is planning to conduct experiments and tests underground at the WIPP, at the Los Alamos National Laboratory, and at the Idaho National Engineering Laboratory with both simulated waste and TRU mixed waste. These studies are part of the gas generation program and the source-term program, which are designed to provide the following needs for performance-assessment modeling: (1) a gas generation model that predicts the rate at which gas will be generated by the TRU mixed

waste in a disposal room; and (2) an actinide source-term model that predicts the concentrations of actinides that could be dissolved or suspended in brine; and (3) information on quantities and concentrations of volatile organic compounds (VOCs) that may be released from waste containers. The relationship between hazardous waste constituents and the gas and brine will be investigated also.

Models to predict the generation and concentration of gases will be developed from results of laboratory experiments; the adequacy of these models will be assessed by comparing their results with the results of tests conducted on TRU mixed waste in bins underground at the WIPP. The actinide source-term model will be based on the results of laboratory experiments; the adequacy of this model will be assessed against the results of the actinide source-term tests performed at the Los Alamos National Laboratory. Larger scale tests with TRU mixed waste will be conducted underground at the WIPP in a specially designed room called an "alcove"; these tests will characterize gas conditions for disposal rooms.

The *Test Phase Plan for the Waste Isolation Pilot Plant* describes the requirements of 40 CFR Part 191 (except Subpart A); 40 CFR 264, Subpart X; and 40 CFR 268.6 and presents the DOE's approach for demonstrating compliance with these requirements. The Plan then summarizes the rationale for conducting the test phase activities, rather than providing details of the experiments. Although such details will be found in plans developed for individual studies, all the contributing studies for each activity are described and justified in this Plan, including studies that are currently in progress or will be undertaken soon to provide information to support the regulatory compliance assessment.

Chapter 1

Introduction

1. INTRODUCTION

This chapter sets the stage for the Plan: Section 1.1 provides background information and Section 1.2 defines the scope of the Plan.

1.1 BACKGROUND

This section describes the development of the WIPP Project; the design and layout of the WIPP; the WIPP disposal system and its behavior over the long term; and the transuranic waste for which the WIPP is designed. Background information is also provided on the Land Withdrawal Act and on involvement in the Project by the EPA, the State of New Mexico, other applicable regulatory bodies, and oversight groups.

1.1.1 Mission of the WIPP

The U.S. Department of Energy (DOE) was authorized in 1979 (by Public Law 96-164) and funded by the Congress to develop a facility for demonstrating the safe disposal of transuranic (TRU) radioactive wastes generated in national defense activities. The WIPP Legislative Land Withdrawal Act (LWA) of 1992 (Public Law 102-579) provided additional authorization to continue the project under a stipulated statutory process. This facility, called the Waste Isolation Pilot Plant (WIPP), has been developed in New Mexico and is operationally ready to start a phase of testing directed at evaluating the ability of the WIPP to be operated in compliance with regulations concerned with safety both in the short term and the long term. If regulatory compliance is demonstrated and a decision to start disposal is made, following the provisions of the LWA, the WIPP will be used for the permanent disposal of TRU wastes, including TRU wastes containing hazardous constituents (TRU mixed waste).

1.1.2 Description of the WIPP

The WIPP facility has been constructed in southeastern New Mexico (Figure 1-1), 26 miles east of Carlsbad, on land owned by the Federal Government. Prior to October 1992, this land was administered by the U.S. Department of the Interior, Bureau of Land Management. In October 1992, Congress transferred jurisdiction of the land through the LWA to the Secretary of Energy. The site encompasses 10,240 acres in a sparsely populated area, with fewer than 30 people living within 10 miles of the WIPP. The surrounding land is used for livestock grazing, potash mining, and oil and gas production.

Surface structures, the planned underground repository, and four connecting shafts make up the WIPP facility. The purpose of the surface structures is to provide security and safeguards and to accommodate routine operations, administrative activities, and further scientific studies. The surface structures were designed and constructed to service full-scale operations; they can easily accommodate operational aspects of the test phase, including waste retrieval.

A Waste Handling Building is the principal surface structure. It is dedicated to supporting the primary operations—receiving and inspecting waste containers and preparing waste containers for transfer to the underground. This building is divided into an area for handling contact-handled TRU waste, a separate area for handling remote-handled TRU waste, and a support area.

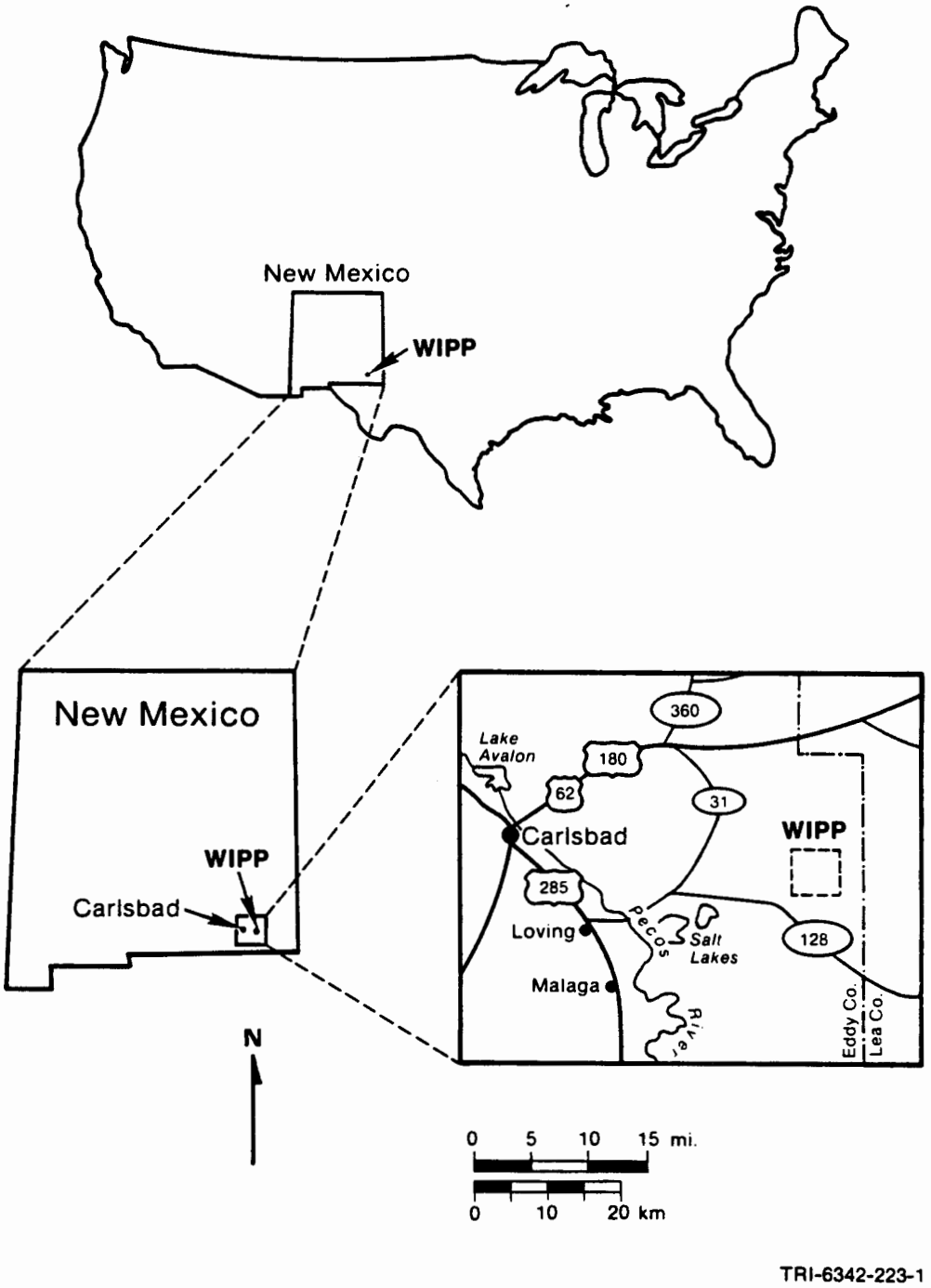


Figure 1-1. WIPP Location Map (after Bertram-Howery and Hunter, 1989a).

The underground excavation is 2150 feet below the surface in the bedded salt of the Salado Formation. It includes a 12-acre area for conducting scientific investigations and experiments in which no waste is used, a mining area with equipment and maintenance facilities, an area in which the waste will be emplaced for permanent disposal if the test phase is successful and a disposal decision is made, and four major interconnecting tunnels that are used for ventilation and traffic. The waste-disposal area is to cover 100 acres and will contain eight separately excavated blocks, or panels, of disposal rooms. Only one of the panels has been excavated. The design and projected operations of the WIPP facility, including the many provisions that have been made for protecting health and safety and the environment, are described in detail in the *Final Safety Analysis Report* (DOE, 1990a) and addenda thereto.

1.1.3 Development in Phases

Because the waste will remain hazardous and radioactive for a very long time, the disposal system must provide safe disposal over many thousands of years. The DOE therefore decided to develop the WIPP in phases, to preclude making premature decisions and to conduct the performance assessments for evaluating long-term safety.

The Early Phases: Siting, Design, and Validation

The process began with a siting phase during which several sites were evaluated and a preferred site was selected on the basis of extensive existing knowledge of the geotechnical setting, which has subsequently been augmented by surface-based testing; a repository was designed; and safety analyses were prepared and reviewed. During this phase, the host rock and the depth for the facility were selected—an interval in the bedded salt of the Salado Formation—and the geologic, hydrologic, geochemical, and rock-mechanics properties of the rocks at the site were studied extensively. The siting phase ended in 1980 with the publication of an environmental impact statement, or EIS (DOE, 1980a), showing that the WIPP would be safe both in the near term and over the thousands of years required for waste isolation. The DOE Record of Decision (DOE, 1981) concluded that the phased development of the WIPP facility is the best alternative of those considered. In the absence of regulations specific to an underground repository for TRU waste, the safety analysis compared predictions of the WIPP's long-term performance against radiation-protection standards developed for the nuclear industry.

Proceeding in a conservative manner, the DOE then decided to begin another phase of study and evaluation. During this phase, known as the site and preliminary design validation (SPDV), two shafts were constructed, an underground testing area was excavated, and various studies were initiated, but none of the studies was conducted with waste. Geologic, hydrologic, and other geotechnical investigations were continued, expanding the site-characteristics data base, and methods for assessing the long-term performance of the WIPP were advanced.

The Construction Phase

During the construction phase, which followed the SPDV phase, the WIPP facility was constructed, additional data about the site were collected, and the tools needed for assessing performance were developed and refined. The surface structures needed to receive waste were built, and considerable underground excavation was completed, including rooms for further experimentation and one panel of rooms designed for permanent waste emplacement. This phase ended with the publication of a final supplemental EIS (DOE, 1990b), and the associated Record of Decision (DOE, 1990c). Both these documents used the data collected since 1980 to examine the potential short- and long-term impacts of the WIPP. The *Final Safety Analysis Report* (DOE, 1990a) was then published.

The geotechnical data collected during the construction phase indicated that some of the characteristics of the site (e.g., permeability) differed from those assumed earlier, which were based on more limited data collected in surface-based studies. However, the extensive analyses of the long-term performance of the disposal system (reported in the supplemental EIS), including analyses that were based on pessimistic assumptions, did not identify any significant impacts on public health and safety. Having reviewed these analyses, the DOE announced its decision (DOE, 1990c) to proceed with the next step in the development of the WIPP—a test phase that includes testing with TRU mixed waste. In this Record of Decision, the DOE made a commitment to prepare, at the end of the test phase, another supplemental EIS that will analyze the long-term performance of the WIPP in light of information gained from the testing. That supplemental EIS will be the basis for the DOE's decision on whether or not to proceed with the disposal phase.

A significant development during the construction phase was the promulgation by the U.S. Environmental Protection Agency (EPA) of environmental standards for the management and disposal of TRU wastes (40 CFR Part 191). In addition, the EPA ruled that facilities used to manage radioactive mixed waste, including TRU mixed waste, are subject to the regulations implementing the Resource Conservation and Recovery Act (RCRA), which are concerned with the management of hazardous wastes.

The Test Phase

As defined in the LWA, the test phase will begin when the first shipment of TRU waste is received for testing at the WIPP. Other "pre-test phase activities," which were initiated by DOE prior to passage of the LWA, will continue through the test phase and into the disposal phase. These "pre-test phase activities" were authorized originally by Section 13 of the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Pub. L. 96-164; 93 Stat. 1259) and reauthorized by the LWA.

The test phase encompasses (1) performance assessments conducted to evaluate compliance with the applicable EPA regulations; (2) studies designed to provide the scientific basis or enhanced confidence in the performance assessments, such as tests with TRU mixed waste and studies to establish that the seals will perform as necessary; and (3) the process by which the decision will be made as to whether TRU waste and TRU mixed waste can be emplaced in the repository for permanent disposal. The overall purpose of the test phase is to develop pertinent information and assess whether the disposal of TRU waste and TRU mixed waste in the planned WIPP repository can be conducted in compliance with the environmental standards for disposal and with the SWDA (as amended by RCRA, 42 U.S.C 6901 *et. seq.*).

The experimental period at the WIPP began in 1980 after completion of the EIS (DOE, 1980a) and will continue throughout the test phase. Scientific and engineering investigations in the underground excavations, laboratory studies, model development, and performance-assessment activities are under way. Tests with TRU mixed wastes have not yet begun. The next phase of the Project will begin when a decision is made to begin disposal or to abandon the Project if the LWA requirements are not met.

Other Phases Defined For The WIPP Project

If the DOE is successful in demonstrating compliance with applicable laws, regulations and requirements and, if the certification and approval requirements of the LWA are met, the Project will go through three other distinct phases: the disposal phase, the decommissioning phase, and the post-decommissioning phase. Specific regulations govern the Project during particular phases, and these

phases will therefore be referred to in the discussions of regulatory compliance in Chapters 2, 3, and 4.

During the disposal phase, the DOE will conduct disposal operations; that is, the receiving, handling, and emplacing of TRU waste and TRU mixed waste in the repository. Both scientific studies and performance-assessment activities will be conducted during this phase, to confirm the results of earlier assessments of long-term performance and to ascertain short-term performance. The period during which radioactive waste will be handled is 25 years. The disposal phase will end when the underground repository has been filled to capacity and the last panel seal that directly interfaces with the waste has been emplaced.

During the decommissioning phase, the repository will be prepared for permanent closure. The surface facilities will be decontaminated and decommissioned. All remaining underground openings will be backfilled with crushed salt, and seals will be installed in selected drifts. Shafts and boreholes will also be sealed. This phase is expected to last no more than ten years.

After decommissioning, the final phase, post-decommissioning, will start. During the initial part of this period, for approximately 100 years, active institutional controls will be employed. These will include active measures such as access control to prevent human intrusion into the repository. Beyond the initial period, passive institutional controls, such as permanent markers, will be employed to deter human intrusion.

1.1.4 The WIPP Disposal System and Its Behavior Over the Long Term

The WIPP disposal system (Figure 1-2) is defined as the controlled area around the planned repository—the natural barriers—and the repository and shaft system, including engineered barriers within the repository. The latter are engineered materials and structures that are expected to substantially delay the movement of radionuclides and hazardous constituents. The disposal unit boundary is defined differently for 40 CFR 268.6 (Figure 1-2). In general, this Plan uses the phrase "disposal system" as defined here (based on the definition in 40 CFR 191), except when a reference is specific to RCRA compliance.

To provide a context for the detailed discussion of performance assessments to demonstrate compliance with the disposal regulations and the RCRA regulations, the paragraphs that follow briefly describe how the WIPP disposal system is expected to behave over the long term, considering the processes and events that are expected to occur over the 10,000-year period of waste isolation specified by the disposal regulations. The system described here is the undisturbed system in which the repository is not affected by human intrusion or unlikely natural events. In describing this system, a number of potentially disruptive events and processes were considered, and were either included in the scenario or eliminated. Those processes included in the scenario (because they are expected to happen), are erosion, sedimentation, climate changes, seismic activity, and shallow salt dissolution at the contact between the Salado and the Rustler Formations (Figure 1-3). Because none of these events or processes has been found to significantly affect the long-term performance of the planned repository, the undisturbed scenario describes processes within the repository as the system equilibrates.

Prior to decommissioning, the waste-disposal panels, drifts, and the experimental area (Figure 1-4) will be backfilled and the drifts and shafts will be sealed. Initially, free brine will not be present within the disposal area, and void space above the backfilled waste will be air-filled (Figure 1-5a). Brine seepage from the Salado Formation could fill fractures in the anhydrite layer (Marker Bed (MB) 139) immediately beneath the disposal area (Lappin et al., 1989; Rechard et al., 1990).

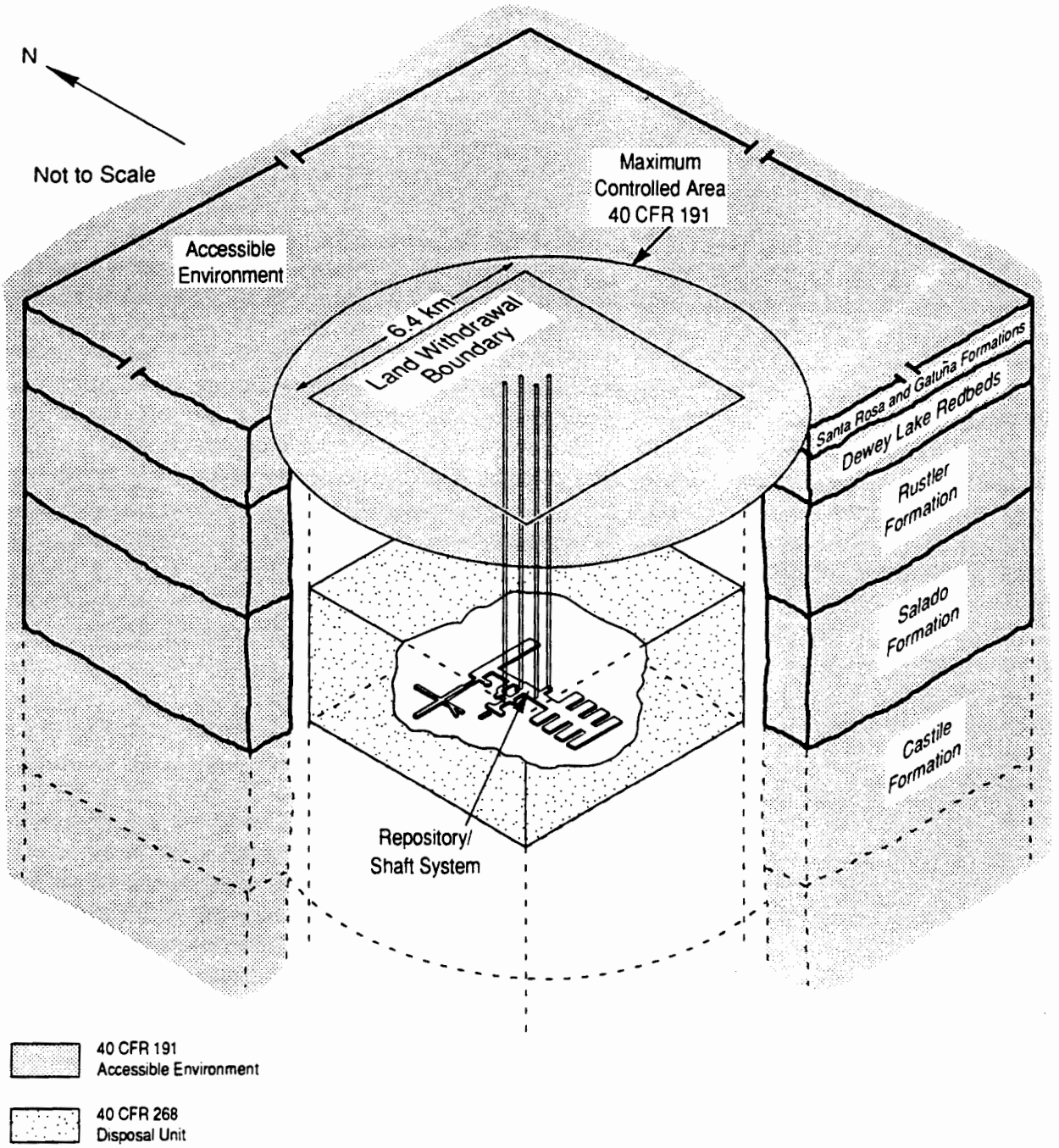


Figure 1-2. Artist's Concept of the WIPP Disposal System, Showing the Controlled Area and Accessible Environment for 40 CFR 191 and the Test-Phase Disposal Unit Boundary for 40 CFR 268.6. (After Bertram-Howery and Hunter, 1989).

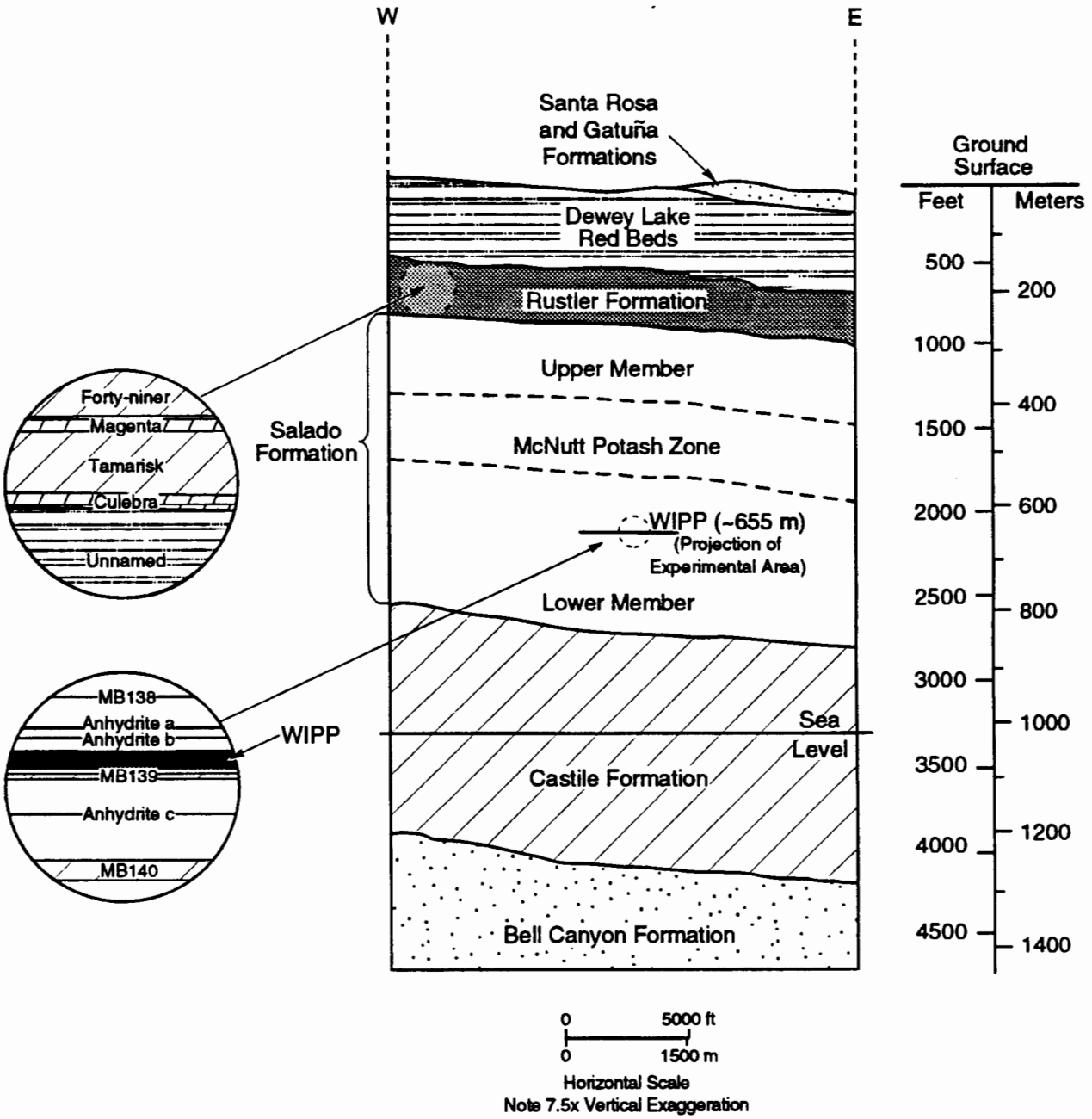


Figure 1-3. Generalized WIPP Stratigraphy Across the Land Withdrawal Area (After DOE, 1980b).

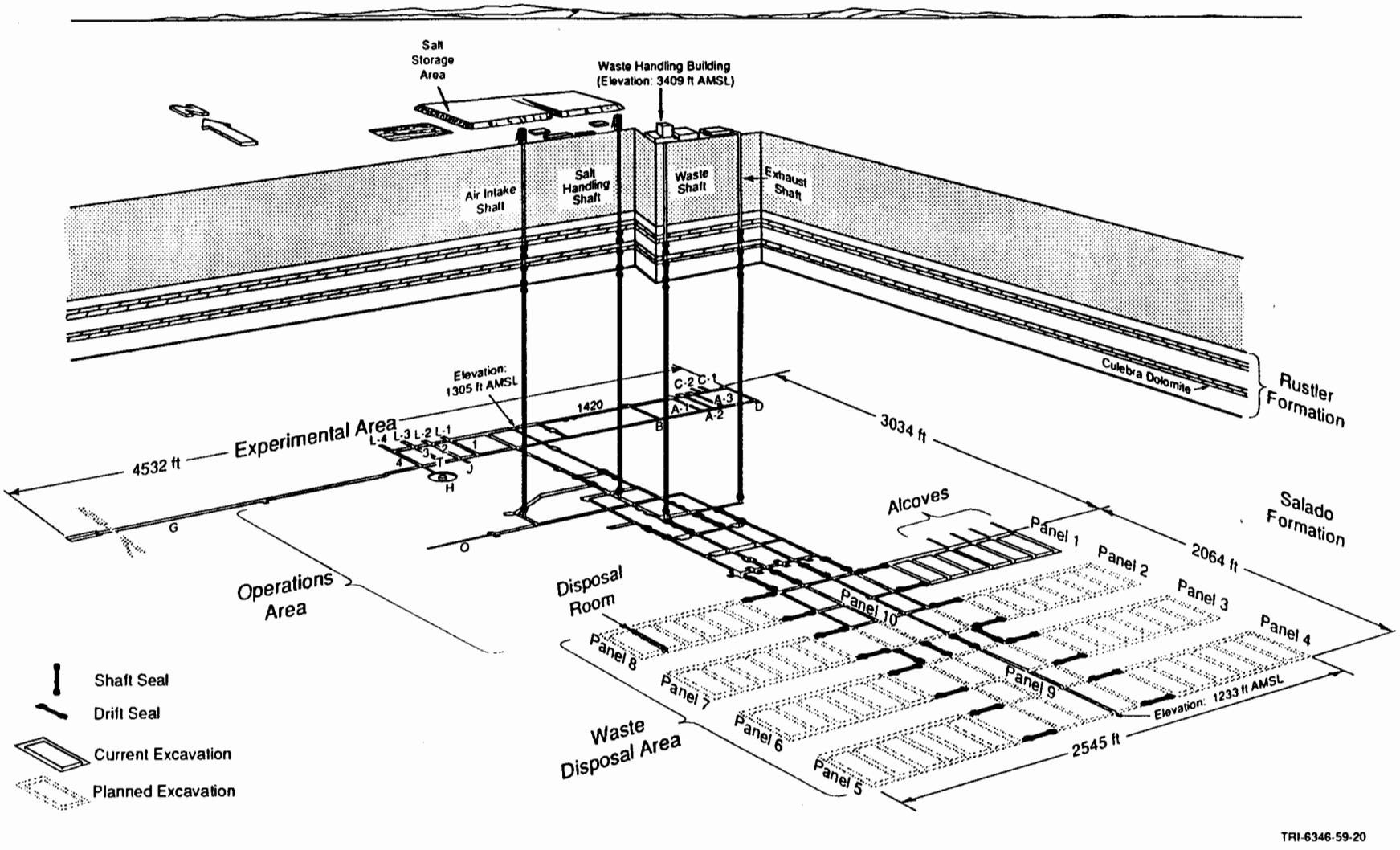


Figure 1-4. Three-Dimensional View of the WIPP Showing Surface Facilities, Shafts, and Underground Workings (Repository Footprint).

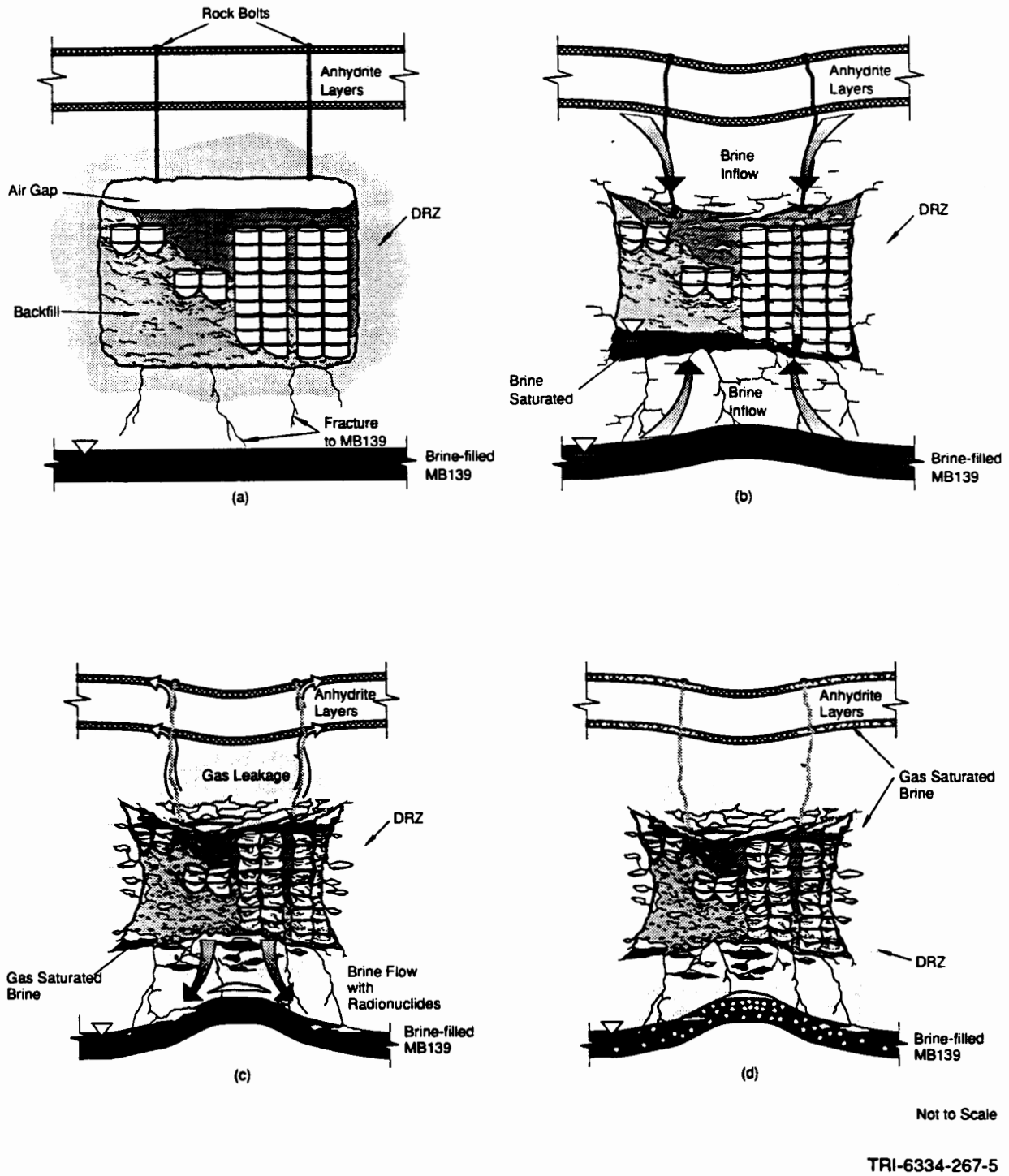


Figure 1-5. Hypothesized Episodes in Disposal Area During Undisturbed Conditions. This drawing shows (a) initial conditions after decommissioning; (b) conditions after room creep closure and brine inflow; (c) conditions after gas generation, brine outflow, and room expansion; and (d) final conditions with gas-filled room surrounded by gas-saturated brine (Rechard et. al., 1990).

As soon as excavations are opened, because of the decrease in the confining pressure on the salt around the rooms, the salt begins to creep inward and close the openings (Figure 1-5b). Modeling of salt creep indicates that creep closure of rooms that are not reinforced and the resulting consolidation of the waste in the rooms could be largely complete within 100 years (Tyler et al. 1988; Munson et al., 1989a, 1989b). Portions of the access drifts and the lower parts of shafts will be filled with preconsolidated, crushed salt (Stormont et al., 1987; Borns and Stormont, 1988; Nowak et al., 1990). Because of the high lithostatic pressures at the planned repository depth, salt creep is expected to exert sufficient pressure on the crushed salt to consolidate the material into low-permeability seals with properties similar to those of the host rock. Portions of the upper parts of the shafts will also be filled with salt, but pressure is not expected to be sufficient to cause the same degree of consolidation as is expected in lower portions of the shafts.

Gas generation is an important process for the undisturbed scenario. Moisture in the planned repository, either inherent in the waste or seeping in from the Salado, can corrode metals in the waste and metallic waste containers themselves, consuming water and generating gas during the process. Radiolysis also will generate gases. In addition, because microbes transported into the repository with the waste are expected to be viable under sealed-repository conditions (Brush and Anderson, 1988), organic materials in the repository will biodegrade with concomitant generation of gases. Some gas may disperse into the surrounding anhydrite layers. Continued gas generation could increase pressure within the repository sufficiently to reverse brine inflow and partially or completely desaturate the waste-disposal area (Figure 1-5c). High pressure may also halt and partially reverse closure by salt creep. In the undisturbed final state, the disposal area could have significant porosity and be gas-filled rather than brine-filled (Figure 1-5d).

All of the major processes active in the waste-disposal area are linked, and all are rate- and time-dependent. For example, creep closure will, in part, be a function of pressure within the planned repository. Pressure will, in turn, be a function of the amount of gas generated and the volume available within the repository and the surrounding Salado Formation for gas storage. Gas-storage volume will be a function of closure rate and time, with storage volume decreasing as consolidation continues. Time and rate of gas generation, therefore, will strongly influence repository pressurization and closure. Gas generation rates will be dependent on specific reaction rates and the availability of reactants, including water. Some water can be generated by microbial activity (Brush and Anderson, 1988). Additional water will be provided by brine inflow. Brine inflow will depend in large part on repository pressure, so the gas generation reactions that require water could be partially self-buffering.

A possible pathway for gas and ground-water flow, and hence hazardous constituent and radionuclide transport, is through interbeds above and below the waste-disposal panel (Figure 1-6), and then up the shafts and into the Culebra (SNL, 1991). Gas, brine and waste constituents could enter the interbeds either through fractures in salt or directly as a result of rooms and drifts intersecting the interbeds. The pressure gradient between the planned repository (near lithostatic pressure, approximately 15 Mpa including waste-generated gas pressure) and the Culebra (at hydrostatic pressure, approximately 1 Mpa) could tend to force brine from interbeds above and below the panel along fractures in the interbeds to the base of the shaft. The permeability of the seals in the lower portion of the shaft will control the upward flow of gas and brine. Hence, the shaft seals control the movement of hazardous constituents as well as radionuclides up the shafts.

1.1.5 Transuranic and Transuranic Mixed Wastes

Transuranic wastes are laboratory and process wastes that contain alpha-emitting radionuclides of atomic number greater than 92 (e.g., the radioactive isotopes of plutonium), have half-lives longer

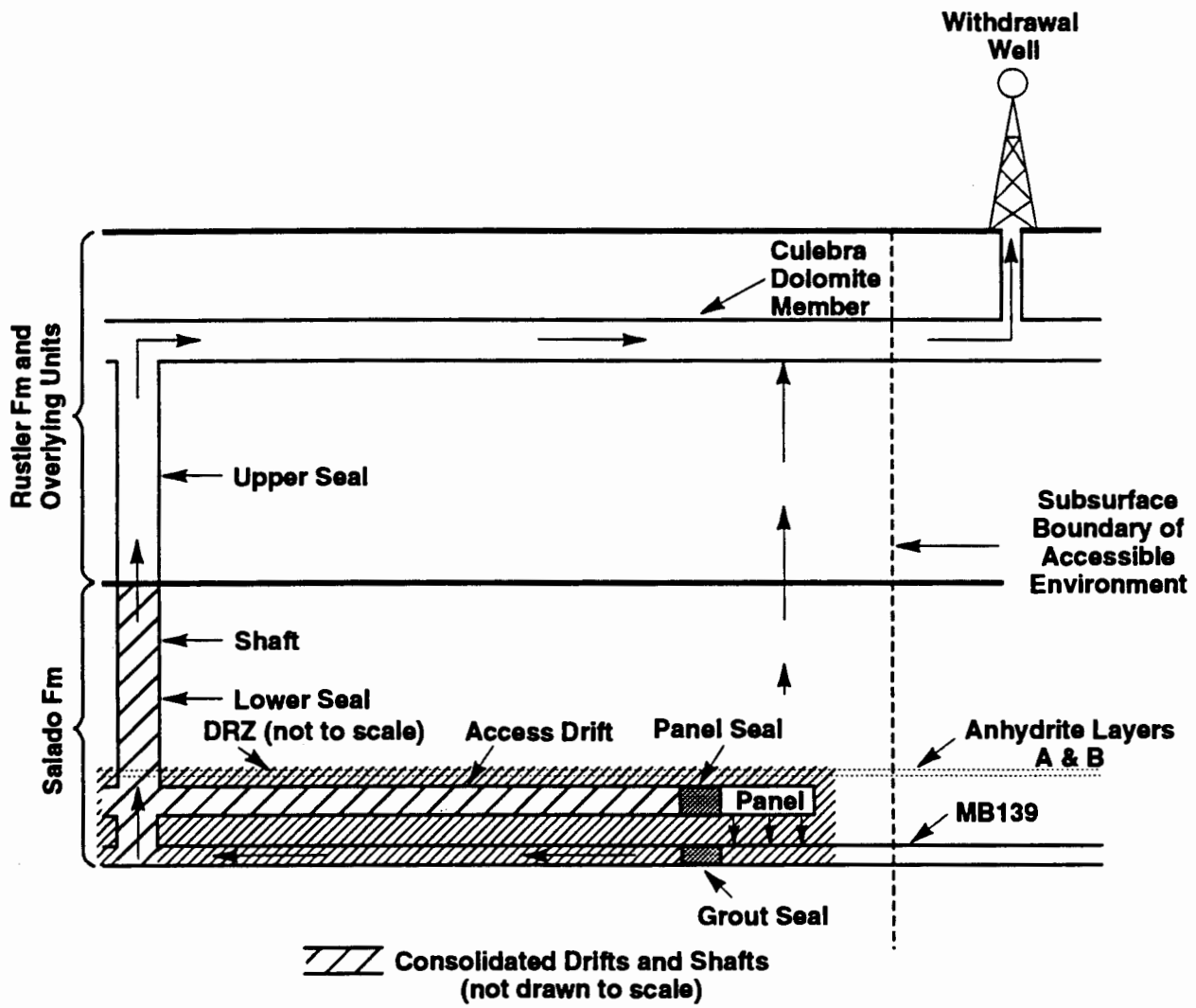


Figure 1-6. Conceptual Model Used in Simulating Undisturbed Performance (SNL, 1991).

than 20 years, and are present in concentrations greater than 100 nanocuries per gram of waste. Transuranic wastes that contain non-radioactive hazardous constituents are called "TRU mixed wastes." Transuranic and TRU mixed wastes are generated primarily in national-defense activities such as the fabrication of nuclear weapons at DOE facilities, (e.g., the Hanford Reservation in Washington; the Idaho National Engineering Laboratory in Idaho; and the Rocky Flats Plant in Colorado). These wastes are stored at the sites where they are generated or at the Idaho National Engineering Laboratory and the Nevada Test Site.

Almost all TRU waste intended to be disposed of at the WIPP is called "contact-handled transuranic waste" (CH TRU waste) because it can be safely handled without shielding other than that provided by the waste container. This contact-handled transuranic waste is packaged in 55-gallon steel drums or in metal boxes. For the waste to be classified as contact handled, the maximum radiation level (the dose rate) at the surface of the waste container cannot exceed 200 millirem per hour. The contact-handled waste comes in a variety of forms, ranging from unprocessed laboratory trash (e.g., paper, glassware, gloves, boots) to solidified sludges from the treatment of liquids.

About 3 percent of transuranic waste is called "remotely handled transuranic waste" (RH TRU). In addition to alpha particles, this waste emits penetrating radiation (beta particles and gamma rays). The surface radiation level on containers of this waste exceeds 200 millirem per hour, and therefore this waste must be handled and transported in shielded casks. The LWA specifies that no TRU waste received at the WIPP may have a surface radiation dose rate higher than 1000 rem per hour and no more than 5 percent by volume of the remotely-handled TRU waste received at the WIPP may have a surface dose rate higher than 100 rem per hour.

For the test phase, the DOE will use only contact-handled TRU mixed waste. No remotely-handled waste will be used in any of the tests at the WIPP, as stipulated by the LWA.

A significant fraction of the TRU waste stored or expected to be generated is mixed waste that contains chemicals and materials classified as hazardous in regulations implementing the RCRA. Examples of these hazardous substances are solvents (e.g., carbon tetrachloride) and metals (e.g., cadmium, lead).

The quantity of TRU waste currently in storage is approximately 2.3 million cubic feet (DOE, 1992b). The total capacity of the WIPP, as specified in the LWA, is 6.2 million cubic feet. Wastes to be generated in the future will include wastes from national-defense programs similar to those that produced the existing wastes; TRU wastes and TRU mixed wastes will also be produced during decontamination and decommissioning of various DOE facilities.

1.1.6 The WIPP Land Withdrawal Act

Authorization to start receiving TRU mixed waste at the WIPP for the test phase is given by Public Law 102-579, signed by the President on October 30, 1992. This law is called the "Waste Isolation Pilot Plant Land Withdrawal Act" because it permanently withdraws the Federal lands on which the WIPP is located from the public domain. The LWA addresses a broad range of concerns related to the WIPP Project, including the test phase, disposal operations, compliance with disposal regulations, compliance with environmental laws and regulations, waste retrievability, mine safety, transportation, access to information, and economic assistance and miscellaneous payments to the State of New Mexico. The paragraphs that follow summarize the provisions that most directly pertain to the test phase.

In Sections 5 and 6, the LWA addresses the test phase. Section 5 requires the DOE to submit a test phase plan and a waste retrieval plan to the Administrator of the EPA within 7 months of the date of enactment. A notice that these plans have been submitted is to be published in the *Federal Register*, and the public is to have an opportunity for access to the plans. The EPA is to determine, in a rulemaking, whether the *Test Phase Plan for the Waste Isolation Pilot Plant* is to be approved or disapproved. The Plan is to be approved if the activities described are directly relevant to a certification of compliance with the final disposal regulations or to compliance with the Solid Waste Disposal Act (SWDA) (as amended by RCRA, 42 U.S.C. 6901, *et. seq.*). If the Plan is not approved, in whole or in part, the DOE may submit a revised Plan to the EPA for review and approval. Furthermore, the DOE may submit modifications to the Plan, but any revisions or modifications require EPA approval through rulemaking.

Section 6 authorizes the test phase activities to be conducted in accordance with the *Test Phase Plan for the Waste Isolation Pilot Plant*, if it has been approved by the EPA, and if certain other conditions have been met, although it limits the wastes that may be transported to or emplaced in the WIPP during the test phase. Section 6 also requires the DOE to publish during the test phase a biennial performance-assessment report, consisting of a documented analysis of the long-term performance of the WIPP, and to respond in writing to comments on the report, if submitted, by the State, the EPA, the National Academy of Sciences (NAS), or the Environmental Evaluation Group (EEG). The long-term performance of the WIPP is interpreted to mean its performance as measured against the final disposal regulations of 40 CFR 191 and the RCRA regulations of 40 CFR 268.6.

Section 8 of the LWA establishes the disposal regulations by reinstating 40 CFR 191, Subpart B (with certain exceptions that will be resolved by the EPA in issuing final regulations) for all disposal sites other than those required to be characterized under section 113(a) of Public Law 97-425. Section 8 also requires the EPA to issue final disposal regulations within six months; this section requires the EPA to propose criteria for certifying compliance with the final disposal regulations within one year and to finalize the criteria within two years. The Secretary of Energy is to submit an application for certification of compliance with the final disposal regulations within seven years of first receipt of waste at WIPP (for the test phase), with a total time limit of ten years for the EPA to certify compliance.

These three sections of the LWA determine the scope of the *Test Phase Plan for the Waste Isolation Pilot Plant* and establish a cyclical approach to incorporating the results of the test phase activities into evaluations of long-term performance.

The Act requires all TRU mixed waste emplaced in the WIPP during the test phase to be retrievable and specifies the circumstances under which the TRU mixed waste must be retrieved. The *Waste Retrieval Plan for the Waste Isolation Pilot Plant* (DOE, 1993a) describes how and under what conditions the wastes will be retrieved.

1.1.7 Involvement by the State of New Mexico, the U.S. Environmental Protection Agency, Other Regulatory Bodies, and Oversight Groups

After the WIPP was authorized by the Congress (Public Law 96-164), the DOE and the State of New Mexico entered into an agreement for consultation and cooperation (DOE, 1981). This agreement was amended in November 1984, August 1987, and March 1988. The agreement specifies various requirements imposed on the DOE in regard to the development and operation of the WIPP and provisions for the State's involvement in the WIPP program, including provisions for oversight and consultation. The agreement has specific requirements for waste retrievability and requires the DOE to conduct separate demonstrations of the retrievability of contact-handled and remote-handled TRU

mixed wastes. New Mexico exercises its oversight and monitoring functions through various State agencies, such as the New Mexico Environment Department (NMED) and the New Mexico Bureau of Mines.

Specific provisions for the involvement of the State in the WIPP test phase are included in the LWA. For example, the State is to provide periodic oversight of compliance with the SWDA (as amended by RCRA, 42 U.S.C. 6901 *et. seq.*), may review the performance-assessment reports that the DOE is required to prepare every two years, and evaluate annually the DOE's basis for determining waste retrievability. The State, through the NMED, is authorized by the EPA and responsible for reviewing the WIPP RCRA permit application and for issuing a RCRA permit to the DOE for the WIPP Project.

Several Federal agencies are assigned specific regulatory and oversight responsibilities by the LWA, with the dominant role being given to the EPA. The others are the Mine Safety and Health Administration and Occupational Health and Safety Administration (U.S. Department of Labor), National Institute of Occupational Safety and Health (U. S. Department of Health and Human Services), Nuclear Regulatory Commission, and the Bureau of Mines (U.S. Department of the Interior).

External oversight also includes safety reviews by the Defense Nuclear Facility Safety Board and inspection by the State Mine Inspector from the New Mexico Bureau of Mines.

Since the late 1970s, the WIPP program has been under the oversight of the EEG, an independent body of technical experts, established by the Congress (Pub. L. 100-456) and funded by the DOE. The EEG is responsible for conducting an independent technical review and evaluation of the WIPP Project. The EEG has reviewed and commented on all major program developments and documents, and its recommendations have had a significant effect on the program. EEG specialists have access to the WIPP underground workings and are able to monitor the work. The EEG is expected to provide continuing oversight during the test phase and is given specific authorities by the LWA.

In addition, the WIPP program has been repeatedly reviewed by the NAS, which is given continued review authority for the WIPP test phase under the LWA. Further, the DOE frequently calls on the technical expertise of outside experts. During the test phase such expertise will be used in evaluating the results of the experimental program and in conducting performance assessments.

1.2 SCOPE OF THE TEST PHASE PLAN

The scope of the *Test Phase Plan for the Waste Isolation Pilot Plant*, as discussed above in Section 1.1.6, is established by Sections 5, 6, and 8 of the LWA.

The objective of the test phase is to evaluate the ability of the WIPP disposal system to comply with the short-term requirements of RCRA as specified in 40 CFR 264 Subpart X and 40 CFR 268.6 and with the long-term requirements of RCRA as specified in 40 CFR 268.6 and with the long-term requirements of the final disposal regulations as proposed in 40 CFR 191, Subparts B and C.

Section 5 of the LWA also identifies the objective of the *Test Phase Plan for the Waste Isolation Pilot Plant* in the Standards for Approval (section 5(d)(2)(A)), which is to show that the test phase will provide data that are directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA (as implemented by RCRA regulations). The activity programs and supporting studies described in this Plan are the DOE's best current estimate of the research, development, and design work that will provide the information directly relevant to a

certification of compliance with the final disposal regulations or to compliance with the RCRA. The LWA reinstated 40 CFR 191, Subpart B for WIPP as issued on September 19, 1985, except for the remanded aspects of sections 191.15 and 191.16. On February 10, 1993 the EPA proposed final disposal regulations for WIPP. The EPA has not yet established criteria for certification of compliance with the final disposal regulations as required by the LWA. As the certification criteria are developed by the EPA and understood by the DOE, additional studies may be proposed to provide required data for demonstrating compliance with the final disposal regulations. Similarly, the EPA may, in the process of evaluating applications relevant to RCRA, identify additional data that are needed to demonstrate compliance. However, the DOE believes that the currently planned activities are broad enough in scope to support demonstrations of compliance with each of these regulations as they are currently understood. The DOE will review the program in light of the final disposal regulations and the associated certification criteria, when they are available. If during conduct of the test phase, the DOE should ascertain that the necessary information can be obtained without performing all the studies described here, or that additional information is required that can be obtained under existing activities, the scope of the test phase will evolve appropriately. A formal modification to this plan will be submitted to the EPA if new activities are proposed that are outside the objectives of activities described in Chapters 3 and 4 or that change the quantities and types of transuranic wastes or transuranic mixed wastes discussed in this *Test Phase Plan for the Waste Isolation Pilot Plant*.

The LWA defines "test phase activities" to mean the testing and experimentation activities to determine the suitability of WIPP as a repository for the permanent isolation of TRU mixed waste. For the purposes of this Plan, "activity" means a set of studies (including field or laboratory tests and experiments, modeling, and analyses) designed to provide information about a subsystem of the WIPP disposal system or about events that may affect the disposal system.

By authorizing the EPA to determine, in a rulemaking procedure, whether the information provided by the test phase activities is directly relevant to a certification of compliance with the final disposal regulations or to compliance with RCRA, the LWA authorized EPA to evaluate the relevance of the information. As defined by DOE, information gathered through test phase activities is relevant to certification of compliance with 40 CFR 191, or to compliance with 40 CFR 268.6 and 40 CFR 264 Subpart X, if it meets either of the following criteria:

- Information is relevant if it is pertinent to <u>developing an understanding</u> of or to <u>predicting</u> effects of parameters, processes, and events important to the assessment of and determination of compliance with the regulatory requirements. Parameters, processes, and events include the design basis performance of the facility and disposal system, waste characterization, waste interactions, and human intrusion or predictable future events.

- Information is relevant if it improves the confidence in technical description (conceptual model) of a parameter, process or event and its representation in compliance assessments.

Relevant information can be further classified as necessary and/or sufficient for compliance demonstrations. Information is necessary if it is specifically required by a regulation or statute, or if it is required by the regulator or the regulatory process to demonstrate, evaluate, or maintain compliance. A sufficient amount of information has been obtained when the DOE, and the regulatory agency, are satisfied that a compliance demonstration provides an acceptable level of confidence in the data, models, and analyses and meets the technical and quality requirements of the regulations.

Discussions regarding what information is necessary and/or sufficient, will occur between the DOE, the regulatory agencies, the public, and other stakeholders during the various EPA rulemakings, compliance certification and determination, and WIPP facility permitting activities.

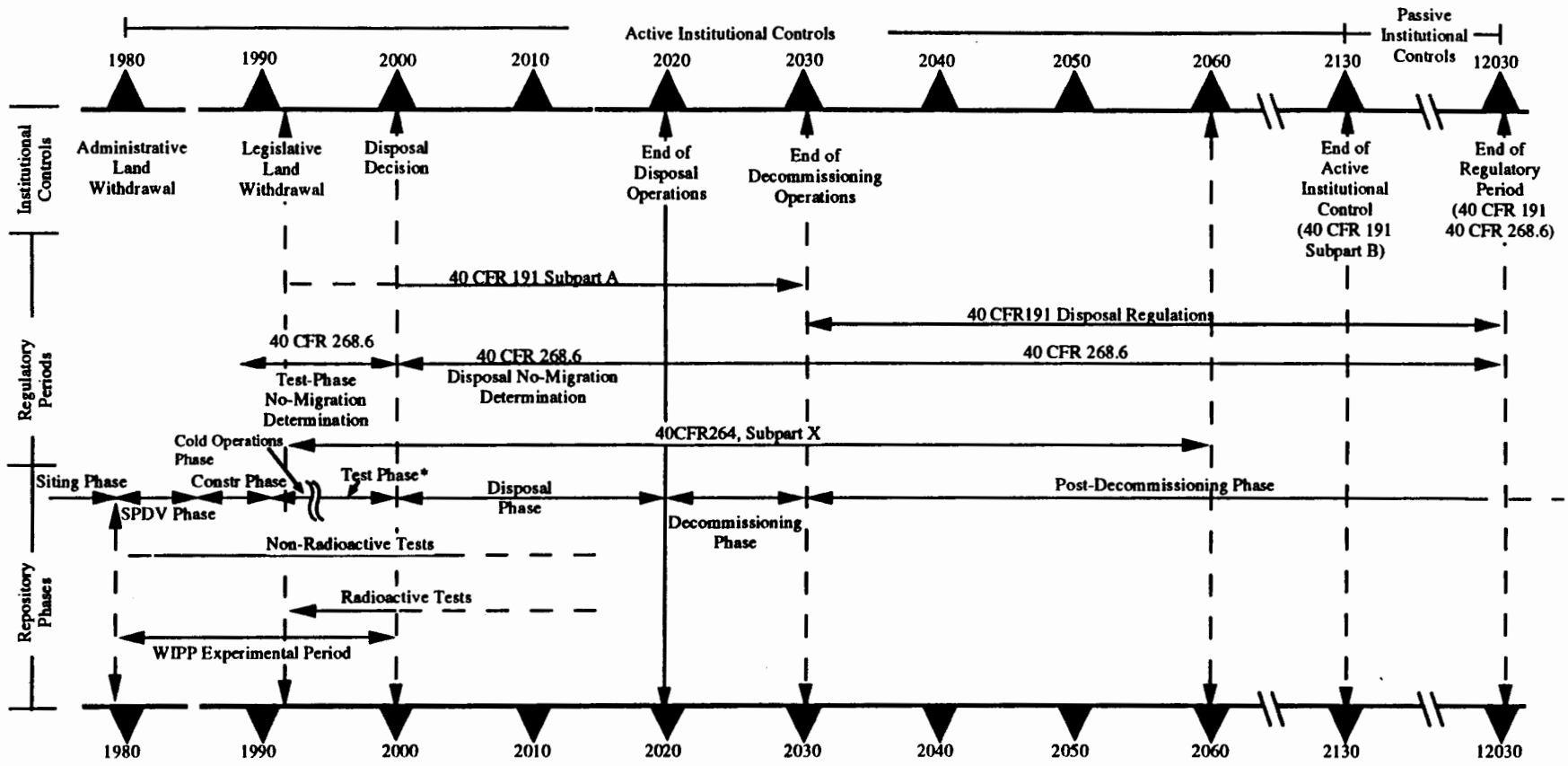
As an example, application of the definitions of these three terms, the DOE has determined that information from the Culebra Dolomite Member of the Rustler Formation is relevant to understanding the process of radionuclide movement toward the accessible environment. Certain specific data sets are necessary; one such data set is the sorptive property of the rocks. The DOE will consider it has sufficient information on sorption in the Culebra when it has established the range of parameter values and understands their uncertainty so that the effects of sorption in the Culebra on disposal-system performance can be predicted. The process of obtaining the requisite information is included in the *Test Phase Plan for the Waste Isolation Pilot Plant*, and will be discussed with the regulatory agencies, the public, and other stakeholders in the future.

In response to the LWA, the DOE has prepared this Plan and the *Waste Retrieval Plan for the Waste Isolation Pilot Plant* (DOE, 1993a) for submittal to the EPA. In addition, two other, supporting documents were also prepared. They are the *Gas Generation and Disposal Room Source-Term Program: Technical Needs Assessment for the WIPP Test Phase* (DOE, 1992a) (that document contains details about the gas generation and source-term programs and is referred to as the "Technical Needs Assessment Document" or TNAD), and the *Waste Characterization Program Plan* (WCPP) (DOE, 1992c). The LWA only specifies that the *Test Phase Plan for the Waste Isolation Pilot Plant* and the *Waste Retrieval Plan for the Waste Isolation Pilot Plant* (DOE, 1993a) be submitted to the EPA for approval. However, the DOE believes that the other two documents will supply additional information that will be of value to the EPA and the public. While these four documents are current relative to the latest understanding of the natural setting and the man-made WIPP facilities, they are not exhaustive in their discussion of the information and data that have been collected during the past 14 years. The new and ongoing studies described in this Plan are based on the results of the many years of extensively documented work (see Appendix B).

1.2.1 Applicable Regulations

The key regulations for the *Test Phase Plan for the Waste Isolation Pilot Plant* as identified above are the environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes promulgated by the EPA in 1985 as 40 CFR Part 191 (EPA, 1985c), including revisions proposed in 1993 (EPA, 1993), and the regulations (40 CFR Parts 264 and 268) implementing the SWDA as amended by the RCRA. The DOE will not be able to start WIPP disposal operations until it demonstrates compliance with these regulations. These regulations, described here along with an overview of the DOE's plans for demonstrating compliance with them, apply to (1) the short term, including the test, disposal, and decommissioning phases and the first thirty years after decommissioning; and (2) the long-term performance after decommissioning. For the short term, environmental and safety analyses will be performed; for the long term, performance assessments will be conducted. The regulations addressed in these analyses and the WIPP phases to which they apply are shown in Figure 1-7.

The environmental standards in 40 CFR 191 are divided into two periods of applicability. Subpart A applies during the test, disposal, and decommissioning phases. It sets limits on the radiation exposures the public may receive from WIPP operations. The LWA does not require consideration of Subpart A in the *Test Phase Plan for the Waste Isolation Pilot Plant*. Moreover, Subpart A is specifically included in the environmental regulations for which compliance must be documented biennially under the requirements of Section 9 of the LWA, which contains specific provisions for compliance with environmental laws and regulations during the test phase. No studies are specifically



NOTE: This schematic is meant to show sequence; the years are identified to indicate relative timing and should not be interpreted as a schedule.

*Test Phase as defined in Legislative Land Withdrawal Act

Figure 1-7. Schematic Showing Relationship of Regulatory Periods and Repository Phases (DOE, 1992b).

required to support compliance evaluations for Subpart A, although data obtained from testing may be used in the Subpart A compliance documentation. Therefore, Subpart A is not within the scope of this Plan. The remainder of 40 CFR 191 applies after decommissioning. It regulates the long-term waste-isolation performance of the WIPP disposal system, and is referred to in the LWA as "the final disposal regulations." A detailed discussion of the disposal regulations and the DOE's plans for determining compliance with these regulations are given in Chapter 3.

Of the applicable RCRA regulations, 40 CFR Part 264 applies during the test, disposal, and decommissioning phases and for a period of 30 years after decommissioning. It establishes technical and environmental performance standards intended to ensure the safe management of hazardous chemical wastes. The regulations in 40 CFR Part 268 restrict the land disposal of untreated, hazardous chemical wastes and apply to all phases of the WIPP. Within these and other parts of the RCRA regulations, only 264, Subpart X and 268.6 require data from testing to support compliance. Therefore, only these two regulations are within the scope of the *Test Phase Plan for the Waste Isolation Pilot Plant*. The requirements of these RCRA regulations and the DOE's plans for determining compliance with them are discussed in Chapter 4.

In addition to the key regulations, the DOE is committed to comply with other applicable Federal environmental laws and regulations and State regulations pertaining to public health and safety, and the safety of workers (e.g., the National Environmental Policy Act of 1969). The applicable regulations and the DOE's plans for compliance are discussed in the final supplemental EIS for the WIPP (DOE, 1990b).

The LWA requires the DOE to certify the safety of test-phase activities. Also, as mentioned previously, every two years the DOE must submit to the EPA documentation of continued compliance with applicable environmental laws with all regulations promulgated under these laws, (except 40 CFR 191, Subparts B and C), and with all permit requirements under these laws. In addition, the DOE is to biennially submit to the State of New Mexico documentation of continued compliance with the RCRA. Finally, every five years after initial receipt of waste for disposal, the DOE must submit to the EPA documentation of continued compliance with the final disposal regulations.

1.2.2 Focus on Compliance

Section 5(b) of the LWA specifies that the *Test Phase Plan for the Waste Isolation Pilot Plant* shall (1) set forth the test phase activities to be conducted at WIPP, (2) specify the quantities and types of TRU mixed waste required for such activities, (3) provide a detailed description of how the test phase activities will provide information directly relevant to a certification of compliance with the final disposal regulations or to compliance with the SWDA, and (4) include justification for all such activities. Hence, this Plan emphasizes evaluating compliance with the pertinent regulations and describes the activities supporting those evaluations. Activities to be conducted at the WIPP facility and at laboratories associated with the WIPP Project are described in this *Test Phase Plan for the Waste Isolation Pilot Plant*. Characterization of the TRU waste inventory at the generator sites is described in the *Waste Characterization Program Plan* (DOE, 1992c) and details of characterization activities are, therefore, not included in this Plan.

Chapter 2 discusses the regulatory requirements and how the DOE will demonstrate compliance with the final disposal regulations and the RCRA. The test phase activities are designed to provide information directly relevant to these demonstrations. The compliance program for each regulation is based on the regulatory requirements and the compliance approach developed to satisfy those requirements. Some activities involve tests with TRU mixed wastes, but most do not. Information to be gained from studies that do not involve wastes is equally important to demonstrating compliance as

information that will be gained from the tests with wastes. An overview of the activities is provided in that chapter.

The methodology that the DOE has developed for predicting the long-term performance of the WIPP disposal system to demonstrate compliance with the quantitative requirements of the disposal regulations is called performance assessment. Details of the performance-assessment methodology are given in Chapter 3. A similar methodology using data common to both modeling programs will be employed to satisfy the long-term performance requirements of 40 CFR 268.6. Chapter 4 provides details of the compliance programs for RCRA, including 40 CFR 268.6 and 40 CFR 264, Subpart X.

Information needs for demonstrating compliance are categorized by the part of the disposal system (natural barriers or repository and engineered barriers), by the effects of the wastes (waste interactions), or by significant events affecting the disposal system (human intrusion). Activities have been designed to provide information about various subsystems or components of these categories. Chapters 3 and 4 include descriptions of these activities, presenting them as integrated programs each comprising several studies of the phenomena contributing to the performance of the particular subsystem or component, or response of the disposal system to the event.

The individual studies are described in Chapter 5. That chapter is organized by the categories of information needs, and within the information needs by the activities that the studies support. The contributing studies for each activity are described and justified, including studies that are currently in progress or will be undertaken soon to provide information to support the regulatory compliance assessments for the WIPP. Extensive investigations (primarily site characterization and repository design) and analyses have been completed. In general, completed work is not described and status of ongoing work is not reported in Chapter 5.

Readers who wish to become familiar with previous work, its status, and the context of its incorporation into analyses and assessments are referred to the FSEIS (DOE, 1990b), NMVP (DOE, 1989), and the three completed preliminary performance assessments (Bertram-Howery, et al., 1990; SNL, 1991; and SNL, 1992). The performance-assessment reports describe the natural setting of the WIPP site as it is incorporated into the performance assessment. This will aid the reader in understanding the need for hydrologic and geologic activities discussed in Chapters 3 and 4 of this Plan. Additional information about the WIPP facility from an operational safety perspective can be found in the *Final Safety Analysis Report: Waste Isolation Pilot Plant*, (DOE, 1990a).

Chapter 2

Regulatory Requirements and Compliance Program

2. REGULATORY REQUIREMENTS AND COMPLIANCE PROGRAM

This chapter describes the three key regulatory requirements for the WIPP disposal system and the DOE's program for demonstrating compliance with those requirements. It begins by summarizing the requirements of the disposal regulations (40 CFR 191, Subparts B and C) and relevant RCRA regulations (40 CFR 268.6 and 40 CFR 264, Subpart X). It then describes the processes for evaluating performance and provides an overview of the experimental program that will be conducted during the test phase to provide the information needed for evaluating compliance. Information is needed from studies of the WIPP disposal system as well as from studies to be conducted in the planned repository and at the Los Alamos National Laboratory and at the Idaho National Engineering Laboratory with TRU mixed waste.

Over the next several years, the DOE will conduct a program of activities directed at assessing the short-term and long-term performance of the planned repository. The purpose of these activities is to evaluate whether compliance with the applicable regulations can be achieved. Because a principal objective is to improve the ability to predict the performance of the repository for both the short term and the long term, most of the test-phase effort will consist of activities that were begun when the WIPP site was selected and have been under way ever since. However, the program also will include tests with waste, which have not been conducted previously.

2.1 REGULATORY REQUIREMENTS

The LWA specifies the standard for EPA's approval of this Plan. Section 5(d)(2)(A) states that the "Administrator shall approve the test phase plan, or any modification to the plan, in whole or in part, if the Administrator determines that the experiments will provide data that are directly relevant to a certification of compliance with the final disposal regulations or to compliance with the Solid Waste Disposal Act (42 U.S.C. 6901 et seq.)." "Disposal regulations" is defined in the LWA to mean "the environmental regulations for the disposal of spent nuclear fuel, high-level radioactive waste, and transuranic waste under section 8" (section 2(7)). Section 8 refers to Subpart B of 40 CFR Part 191; however, in implementing section 8, EPA has proposed a revised Subpart B and a new Subpart C for the final disposal regulations.

The DOE will analyze compliance with the EPA regulations that apply to (1) the short term, including the test, disposal, and decommissioning phases and the first thirty years after decommissioning; and (2) the long-term, after closure. For the short term, environmental and safety analyses will be performed; for the long term, performance assessments, demonstrations, and other actions required by the regulations will be conducted. This Plan addresses 40 CFR 191 (except Subpart A); 40 CFR 268.6; and 40 CFR 264, Subpart X (refer to Figure 1-7). The studies planned for the test phase are directed at obtaining data that are relevant to evaluating compliance with one or more of these regulations.

2.1.1 Final Disposal Regulations (40 CFR 191, Subparts B and C)

Three quantitative requirements are contained in the disposal regulations as proposed by the EPA:

- Containment requirements (40 CFR 191.13) for the "disposal system," which set limits on the probabilities of exceeding specified cumulative releases of particular radionuclides to "the accessible environment" for 10,000 years after disposal. The regulation specifies how to calculate the release limits.

- Individual-protection requirements (40 CFR 191.15), which limit the annual radiation doses delivered to members of the public in the accessible environment for 10,000 years after disposal. The regulation specifies how to calculate the doses. (Note: The EPA is proposing this requirement in its rulemaking to modify the 40 CFR Part 191 regulation. This portion of the *Test Phase Plan for the Waste Isolation Pilot Plant* will be revised if necessary, when the rule becomes final.)

- Ground-water protection requirements (40 CFR 191.24, proposed), which limit the levels of radioactivity in underground sources of drinking water for 10,000 years after disposal. The regulation specifies how to calculate the concentrations. (Note: The EPA is proposing this requirement in a new Subpart C, replacing the original 191.16, in its rulemaking to modify the 40 CFR Part 191 regulation. This portion of the *Test Phase Plan for the Waste Isolation Pilot Plant* will be revised if necessary, when the rule becomes final.)

The "disposal system" consists of the natural barriers within the "controlled area" around the planned repository (see Figure 1-2) and the repository and shaft system, including the engineered barriers within the repository; the latter are materials and structures that are designed to substantially delay the movement of radionuclides toward the accessible environment. The "accessible environment" is defined as the atmosphere, land surfaces, surface waters, oceans, and all of the lithosphere that is beyond the controlled area. Release means movement of radionuclides into the accessible environment.

For the containment requirements (40 CFR 191.13(a)), compliance is to be shown by a prediction that is expressed, to the extent practicable, in a single "complementary cumulative distribution function" (CCDF) displaying probabilities of exceeding certain cumulative releases of radionuclides to the accessible environment. For the individual-protection requirements (proposed 40 CFR 191.15(a)), these predictions are to be expressed as annual committed effective doses to a member of the public in the accessible environment. For the ground-water-protection requirements (proposed 191.24(a)), these predictions are to be expressed as concentrations of radioactivity in underground sources of drinking water in the accessible environment, as specified in 40 CFR 141.

To provide confidence about compliance with the containment requirements, 40 CFR 191.14 specifies the following six "assurance" requirements:

- Active institutional controls over the disposal site should be maintained as long as practicable after waste disposal, but performance assessments should not consider such controls after 100 years.

- After waste disposal, the disposal system should be monitored to detect significant and detrimental deviations from the expected performance, by techniques that do not jeopardize waste isolation, until there are no significant concerns to be addressed by further monitoring.

- Passive institutional controls, such as permanent markers at the disposal site and records, should be used to indicate to future generations the dangers of wastes and their locations.

- Different types of barriers, both natural and engineered, should be used to provide waste isolation.

- In siting a repository, the likelihood of future exploration for irreplaceable or vital natural resources should be considered.

- Disposal systems shall be selected so that the removal of most of the waste should not be precluded for a reasonable period of time after disposal.

2.1.1.1 The Status of the Disposal Regulations

In 1987, the individual-protection requirements (40 CFR 191.15) and the ground-water-protection requirements (40 CFR 191.16) were remanded by a U.S. court of appeals; the court then vacated and remanded all of Subpart B of 40 CFR Part 191 to the EPA. However, the DOE and the State of New Mexico agreed, in a modification to the Agreement for Consultation and Cooperation (DOE and the State of New Mexico, 1981, as modified), that the DOE's plans for regulatory compliance would be based on the 1985 standard until the standard is repromulgated. In preparing to issue a draft revised standard for public comment, the EPA has been considering various changes that have been proposed for all of the quantitative requirements.

The LWA requires the EPA to issue final disposal regulations for the WIPP and other disposal sites by April 30, 1993, except those covered by Section 113(a) of P.L. 97-425. Proposed regulations were published on February 10, 1993. Furthermore, the LWA specifies that Subpart B, as issued in 1985, is in effect except for the three aspects of 40 CFR 191.15 and 16 that were the subject of the remand order. And not later than October 30, 1993, the EPA is to propose criteria that the EPA will use for certifying the DOE's compliance with the final disposal regulations for the WIPP disposal system. The final criteria are to be issued by October 30, 1994. The DOE will continue evaluating performance of the WIPP disposal system against the 1985 standard until the EPA promulgates the final disposal regulations.

For the purposes of this plan, the final disposal regulations proposed by the EPA on February 10, 1993 are considered to be in place and in effect. The DOE recognizes that they are, in fact, only proposed. This Plan will be modified as appropriate to reflect the final disposal regulations.

2.1.1.2 Guidance for Implementing the Disposal Regulations

The performance assessment for the containment requirements of 40 CFR 191.13(a) must evaluate both the "undisturbed performance" (i.e., the predicted behavior of a disposal system, including uncertainties in the prediction, in the absence of human intrusion or the occurrence of unlikely natural events) and the consequences of performance-disturbing events and processes, including human intrusion. For the individual protection requirements (40 CFR 191.15(a)) and groundwater protection requirements(40 CFR 191.24(a)), only undisturbed performance must be evaluated.

The analyses of consequences are also different for the three quantitative requirements. For 40 CFR 191.13(a), potential cumulative releases to the accessible environment over 10,000 years are estimated and the probabilities of their exceeding specified release limits are determined. The performance measure will be a single CCDF showing exceedence probability versus cumulative release. For 40 CFR 191.15(a) as proposed, potential annual releases to the accessible environment will be estimated so that annual committed effective doses resulting from such releases can be predicted. The performance measure will be the best-estimate of the predicted values for each of the 10,000 years of regulatory interest. For 191.24(a) as proposed, potential cumulative releases to the accessible environment over 10,000 years will be estimated so that concentrations of radioactivity in underground sources of drinking water resulting from such releases can be predicted. The performance measure will be the best-estimate of the predicted values.

Thus, to demonstrate compliance with the containment requirements of 40 CFR 191.13(a), it is necessary to estimate the releases of radionuclides that might occur during a period of 10,000 years

after the repository has been sealed. Furthermore, in estimating releases it is necessary to consider all the significant processes and events, including the future potential for inadvertent human intrusion, that might affect the ability of the repository to isolate waste. Moreover, the releases are to be treated probabilistically; it is necessary to estimate probabilities of occurrence for the releases.

The EPA recognizes the difficulties associated with identifying all the events and processes that would be significant during 10,000 years and in making technically convincing determinations of the disposal system's performance. The regulation therefore states (40 CFR 191.13(b)) that "complete assurance" is not expected. What is required is a "reasonable expectation" that a repository would meet the probabilistic limits on releases during 10,000 years. A similar standard is also applied to individual protection (191.15(c) proposed) and ground-water protection (191.24(b) proposed). Though the EPA does not define "reasonable expectation," it does provide supplementary guidance in an appendix to the regulation, giving additional explanations about the level of detail that would be considered sufficient evidence of compliance for each requirement. The EPA recognizes that a reasonable expectation need not depend on rigorous compliance with a quantitative measure; it can incorporate qualitative judgment as well. What the EPA requires is a rational decision, based on "the record before the implementing agency" (i.e., the DOE in the case of the WIPP, see 191.12), that incorporates both quantitative analyses and qualitative judgment.

2.1.2 Resource Conservation and Recovery Act Requirements

The Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984 amended the Solid Waste Disposal Act. RCRA regulates the management of solid wastes, hazardous wastes, and underground storage tanks. Among the regulations implementing the RCRA that are applicable to the WIPP are 40 CFR 268.6 and 40 CFR 264, Subpart X. The regulations require evidence that any of the hazardous components of the waste that are released into the environment do not pose a threat to human health or the environment both in the short term, while testing, disposal, and decommissioning operations are conducted at the WIPP, and over the long term, the thousands of years of waste isolation. The calculations needed to support no-migration predictions for the long term will be based on the same conceptual models (see Section 3.1.1.2) for repository performance as will be used for the disposal regulations.

RCRA applies to the WIPP because a significant fraction of the TRU waste planned to be emplaced in the repository is mixed waste. These are wastes that contain both radioactive materials and hazardous chemicals. The RCRA requirements regulate the hazardous chemical component of the mixed waste.

2.1.2.1 Requirements of 40 CFR 268.6

The 1984 Hazardous and Solid Waste Amendments to the RCRA prohibit the land disposal of untreated hazardous waste. "Land disposal" includes the emplacement of waste in underground mines and salt beds. The land-disposal restrictions (40 CFR Part 268) specify that waste must be treated to diminish its hazard or to reduce the likelihood that its hazardous constituents will migrate into the environment. However, EPA regulation 40 CFR 268.6 allows the disposal of such wastes (referred to as "restricted waste") not meeting specified treatment standards if a petitioner can demonstrate to a reasonable degree of certainty that there will be no migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous. The regulation also requires this demonstration to include an evaluation of the consequences of predictable future events. The no-migration demonstration must be supported by information required by the regulation including information on the waste, the disposal unit site, and plans for monitoring to detect migration at the earliest practical time.

"No migration" has been interpreted by the EPA to mean no movement of hazardous constituents beyond the unit boundary in concentrations exceeding health-based levels (EPA, 1990b). The unit boundary for the WIPP facility during the test phase (see Figure 1-2) has been interpreted to be the Salado Formation within the area controlled by the DOE (EPA, 1990a).

A demonstration "for as long as the waste remains hazardous" is interpreted by the EPA to be sufficient if extended 10,000 years. This interpretation, supported by EPA's position that " . . . for the purposes of determining compliance with RCRA no-migration standards, it is not particularly useful to extend this model beyond 10,000 years into the future" (EPA, 1990b), applies to long-term performance after disposal.

Pursuant to the provisions of 40 CFR 268.6, the DOE submitted a petition for a "no-migration" determination for the WIPP to the EPA in March 1989. With some modification, a revision was submitted in March 1990. A notice proposing to grant a conditional variance for the test phase was published by the EPA on April 6, 1990 (EPA, 1990b), and public hearings on the proposal were held from May 22 through 26, 1990. The final determination was granted by the EPA on November 14, 1990 (EPA, 1990a). The determination applies to the WIPP test phase only.

The no-migration determination allows the DOE to emplace a limited quantity of untreated TRU mixed waste in the WIPP underground for the purpose of testing, as defined in Revision 0 of this Plan (DOE, 1990d). Through its no-migration determination, the EPA imposes several conditions and limitations related to waste characterization, waste retrieval, air monitoring, control of airborne emissions, and reporting.

The EPA's guidance on 40 CFR 268.6 is entitled *No-Migration Variances to the Hazardous Waste Land Disposal Prohibitions: A Guidance Manual for Petitioners* (EPA, 1992). It was published as a draft in July 1992. The manual was prepared by the EPA to assist owners and operators of hazardous waste management facilities who are interested in obtaining a variance from the land-disposal restrictions. The manual provides the EPA's interpretations and suggested procedures for compliance. The DOE has used the EPA's guidance in developing the compliance program.

The DOE plans to submit another petition for a no-migration determination to proceed with the disposal phase. The DOE's planning for the 40 CFR 268.6 compliance program for disposal is enhanced by the successful completion of the *No-Migration Variance Petition* (DOE 1989) for the test phase.

The EPA is planning to revise the no-migration standard. The proposed rulemaking for the revision was published in the *Federal Register* on August 11, 1992. The major change expected from the rulemaking is the definition of health-based levels for the determination of no migration. The DOE will adjust its compliance program as warranted by the final rule.

2.1.2.2 Requirements of 40 CFR 264, Subpart X

Subpart X of 40 CFR 264, "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," provides for the permitting of the underground portion of the WIPP facility as a "miscellaneous unit." Subpart X includes an environmental performance standard for miscellaneous units (40 CFR 264.601). The standard requires that these units be located, designed, constructed, operated, maintained, and closed in a manner that will ensure protection of human health and the environment.

This standard is performance based; it does not prescribe specific technical standards. To demonstrate compliance, the DOE will assess the potential human health and environmental impacts of the management of transuranic mixed waste at the WIPP facility. This assessment is based on evaluating the measures for preventing releases of hazardous constituents and the concentrations of hazardous constituents available for release from the waste, potential pathways for release, potential receptors, and the human health and environmental consequences of any releases. The assessment will use data from studies planned for the test phase, including those with TRU mixed waste. This assessment will address the air, soil, ground-water, and surface-water pathways.

A RCRA permit application for the planned repository was submitted to the New Mexico Environment Department (NMED) to comply with the RCRA permitting requirements and to demonstrate compliance with the technical and performance standards of 40 CFR Part 264 (and applicable State of New Mexico regulations). The permit application is specific to the performance of test phase studies with TRU mixed wastes in the repository.

A RCRA permit will be granted by the State of New Mexico only if the permit application demonstrates that the WIPP can be operated in compliance with the 40 CFR 264, Subpart X environmental performance standard. A RCRA permit for the WIPP will specify operating requirements that must be met by the DOE during the test phase. Prior to the initiation of the disposal phase, the DOE must submit a revised permit application or seek a modification to the RCRA permit.

2.2 COMPLIANCE PROGRAMS

This section describes DOE's programs for evaluating compliance with regulations that apply to the WIPP disposal system in the long term and in the short term. The regulations that pertain to long-term performance are 40 CFR 191, Subparts B and C (as proposed) and 40 CFR 268.6. Those that pertain to short-term performance are 40 CFR 268.6 and 40 CFR 264, Subpart X. These are addressed in this plan.

2.2.1 Program for Evaluating Long-Term Performance

For evaluating compliance with the long-term performance requirements of 40 CFR 191 and 40 CFR 268.6, the DOE will collect data and perform analyses. It will use a technique developed especially for predicting the behavior of geologic repositories over the thousands of years required for waste isolation. This technique is performance assessment—a multi-disciplinary, iterative, analytical process that begins by using available information that characterizes the waste and the disposal system: the design of the repository and its seals and the natural barriers provided by the host rock and the surrounding formations. It identifies the processes (i.e., phenomena that might develop slowly, over long periods of time) and events that might affect the system and examines the effects of these processes and events on the performance of the system. It then estimates the releases of radionuclides and hazardous chemical constituents, considering associated uncertainties. Sensitivity analyses to determine which characteristics of the disposal system or which processes exert the greatest effect on performance are also performed.

The results of performance assessment are used in the 40 CFR 191 compliance program to assess repository behavior and environmental releases relative to the standards. For 40 CFR 268.6, the results form a basis for preparing a no-migration demonstration as part of a petition for a no-migration variance from the land disposal restrictions.

The structure of the DOE's program for assessing the ability of the WIPP disposal system to satisfy the 40 CFR 191 disposal regulations is illustrated in Figure 2-1. Performance-assessment modeling and analysis will provide the quantitative evaluation of long-term radionuclide isolation and containment. Information necessary to simulate long-term performance must adequately represent the disposal system, composed of the natural barriers and the repository with its engineered barriers, as well as the interactions of the waste with the disposal system. The probability of human intrusion and its impacts must also be evaluated for the disposal regulations. Compliance must also satisfy the assurance requirements of Subpart B. The compliance program is described in Chapter 3.

The approaches to evaluating compliance with 40 CFR 191 and 40 CFR 268.6 will be fundamentally similar. For the 40 CFR 191 evaluation, the performance assessment will focus on the release of radionuclides from the controlled area. For the long-term 40 CFR 268.6 no-migration evaluation, the performance assessment will focus on the release from the disposal unit of hazardous chemical constituents.

The structure of the DOE's program to comply with the 40 CFR 268.6 no-migration standard for the long term is illustrated in Figure 2-2. Compliance will be documented in a no-migration variance petition, which will provide all information required by the regulation. Key compliance activities associated with the development of the petition include determining the hazardous constituents source term, modeling the release of hazardous constituents, assessment of environmental risks, performance of uncertainty analysis, and the development and implementation of a monitoring program. Except for monitoring, these activities will be supported by the development of information, categorized into three areas: natural barriers; repository design and engineered barriers; and waste interactions.

The WIPP performance-assessment method has been reviewed by the NAS, the EEG, and experts in and outside the United States. Models have been developed and exercised, and three preliminary assessments of performance for the disposal system have been documented. The results suggest that compliance with the disposal regulations can be achieved, although the data and modeling assumptions need to be further refined and confirmed. These assessments, like all previous performance-assessment exercises (e.g., DOE, 1980a), addressed the performance of the WIPP disposal system in isolating radionuclides. The application that will be submitted to the EPA for certification of compliance with the disposal regulations (40 CFR Part 191, Subparts B and C) will be the first of its kind.

The information developed during the test phase will be used to complete the performance assessments for both regulations. In fact, developing the information base from which appropriate conceptual models and parameter values will be derived (e.g., understanding the uncertainties associated with the performance assessments completed to date) is the principal reason for conducting the test phase, including the experiments with TRU mixed waste.

In addition to supporting DOE's evaluation of regulatory compliance, performance assessments provide guidance to the experimental and testing programs on information needs and priorities and on the statistical adequacy of the available information. The preliminary performance assessments provide estimates of the effectiveness of the design of the planned repository. If a reasonable expectation of compliance with 40 CFR 191 cannot be demonstrated for the WIPP disposal system as it is currently designed, engineered alternatives will be evaluated for their contributions to improving performance (DOE, 1991b).

The current conceptual model of the WIPP disposal system and its expected behavior over the long term, as described in Chapter 1, clearly shows why performance assessment—for both radionuclide isolation (Chapter 3) and the containment of hazardous waste constituents (Chapter 4)—needs the gas

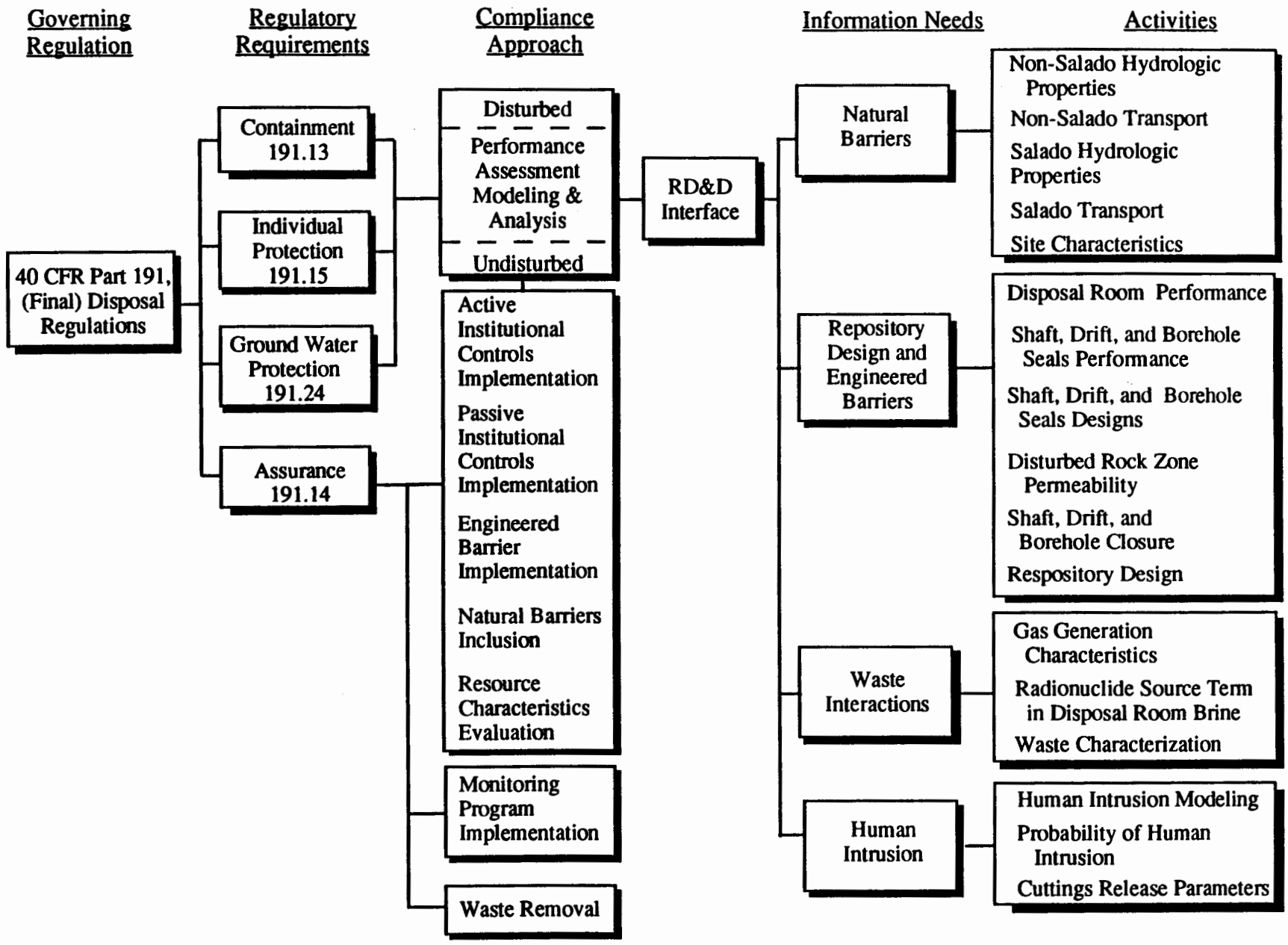


Figure 2-1. Long-Term 40 CFR Part 191 Compliance Program Structure.

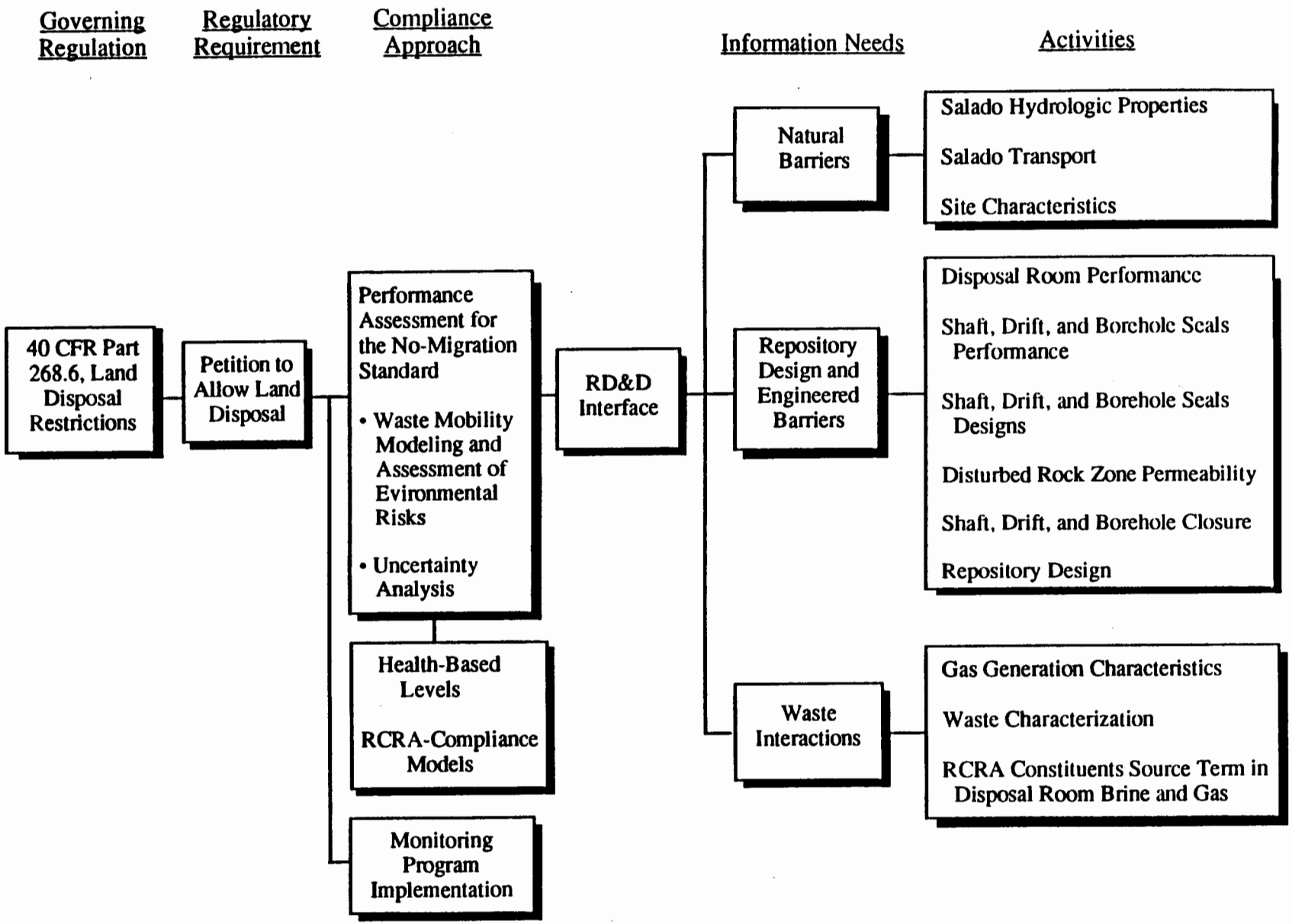


Figure 2-2. Long-Term 40 CFR 268.6 Compliance Program Structure.

generation model. It also shows why an understanding of uncertainties about phenomena such as the consolidation of backfill, the development of fractures in the rock, the behavior of shaft seals, and the hydrologic properties of the host rock and the surrounding units is important to the performance assessment. The experimental and testing program developed for the WIPP is specifically designed to examine these processes and, where feasible, reduce the associated uncertainties.

Compliance with these regulations for long-term performance requires a combination of analyses, design and engineering, and specified actions. A reasonable expectation of compliance with the disposal regulations will be based on extensive information that may or may not appear directly in the calculated predictions of containment or of individual and ground-water protection. The data base of site and waste characteristics will be sufficient to demonstrate an adequate understanding of all important natural processes; to define and defend conceptual models of natural processes; to provide ranges of parameters for use in the calculations; and to assess interaction processes between the waste and the host-rock. The subsystems of the disposal system will be modeled, based on adequate, realistic conceptual models, and using computational models that correctly represent the conceptual models and have been validated to the extent practical, interactions of the subsystems with the wastes and the host rock will be included, and the effects of human intrusion accounted for. Engineered barriers must be designed; their performance analyzed, reviewed, and demonstrated; and their emplacement feasibility established. A similar process is necessary for the markers and barriers that will be relied on to deter human intrusion. Other institutional controls will be planned. A monitoring program will be planned that can detect substantial deviations from predicted performance without impairing the ability of the disposal system to isolate the waste. Compliance with the RCRA requirements will also be based on these types of information, designs, and plans.

2.2.2 Program for Evaluating Short-Term Performance

As discussed previously, the short term is interpreted to include the test phase, the disposal phase, the decommissioning phase, and for 40 CFR 264, Subpart X, a period of 30 years after decommissioning. The DOE has concluded, and the EPA has concurred (EPA, 1990b; EPA, 1990a), that during the test phase, the only credible pathway for the migration of hazardous constituents from the WIPP repository is air transport of volatile organic compounds. This is also expected to be true for the disposal phase and the decommissioning phase.

Accordingly, the evaluation of compliance with the 40 CFR 268.6 no-migration standard during the disposal and decommissioning phases will focus on characterizing the source term and modeling the transport of hazardous constituents through the air pathway. This evaluation will assess the quantities and concentrations of volatile hazardous constituents released from the transuranic mixed waste into the underground air, the natural and engineered barriers to airborne transport of these constituents, and the expected concentrations of hazardous constituents in the exhaust airflow. The expected concentrations will be compared with established health-based levels to evaluate whether compliance with the no-migration standard is achieved.

The structure of the program to demonstrate compliance with the no-migration standard of 40 CFR 268.6 before completion of decommissioning is shown in Figure 2-3. Information regarding natural barriers, the repository design and engineered barriers, and waste interactions will be needed to support this compliance program.

The DOE must also demonstrate that the WIPP facility will meet the environmental performance standard of 40 CFR 264, Subpart X during the short term. This evaluation of compliance will be similar to the short-term no-migration evaluation. However, the potential for human and environmental risks will be evaluated based either on numerical health and environmental standards or

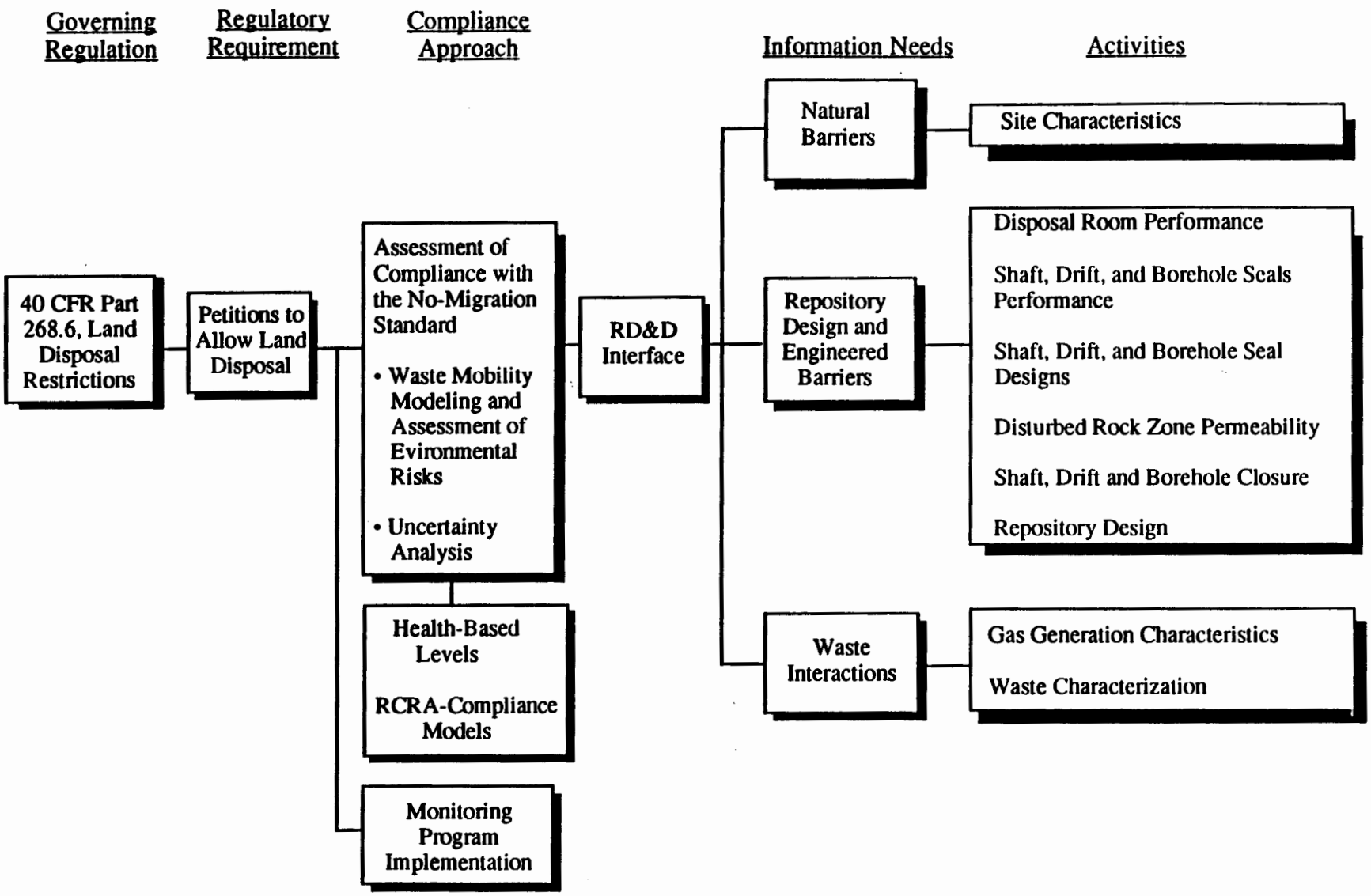


Figure 2-3. Short-Term 40 CFR 268.6 Compliance Program Structure.

on non-numerical performance requirements necessary to protect human health and the environment. This analysis of risk will be performed by evaluating the quantities, concentrations, and toxicities of hazardous constituents available for release to the environment, potential pathways for release, potential receptors, and the consequences of such releases.

The postclosure (post-decommissioning) care period, as specified by regulation (40 CFR 264.117), will have a duration of 30 years. During this period, no air pathway will exist because the underground accessways and shafts will have been backfilled and sealed. No other pathway for the migration of gases or fluids from the underground disposal rooms to the boundary of the waste-management unit is believed to be credible for this 30-year period because migration to the boundary of the unit through the engineered barriers and the host rock is predicted to take millennia. This expectation will be verified during the performance assessment for long-term compliance with 40 CFR 268.6.

The structure of the 40 CFR 264, Subpart X compliance program is described in Figure 2-4. The program includes the evaluation of risks to human health and the environment, supported by the development of information grouped into the same three categories applicable to the 40 CFR 268.6 and 40 CFR 191 programs: natural barriers; repository design and engineered barriers; and waste interactions. The compliance program also includes the development and implementation of programs to satisfy requirements pertaining to monitoring, inspections, response, reporting, corrective action, and postclosure care.

2.3 THE RESEARCH, DEVELOPMENT, AND DESIGN PROGRAM

As described in the previous sections, each of the four compliance programs includes a regulation and its requirements, a compliance approach, information needs that must be met to complete the compliance process, and activities that focus and provide the objectives for the research, development, and design program. These activities are designed to provide information that is relevant to completion of one or more of the four compliance programs. The information is either pertinent to developing an understanding or predicting effects of, or to improving confidence in the technical description of important parameters, processes, or events. The research, development, and design program will ensure that information needed to evaluate regulatory compliance, including data and models, is available to the performance assessments, waste mobility modeling efforts, and the assessment of environmental risks.

The research, development, and design program encompasses laboratory, field, and modeling studies. Some laboratory and field studies will involve transuranic mixed wastes or simulated wastes. Experience with real waste and incorporation of test results obtained from this waste into the pertinent databases will improve the DOE's confidence that interactions between the waste and the disposal system are adequately understood and represented in the four compliance assessments.

2.3.1 Activities and Supporting Studies to Satisfy Information Needs

Each information need will be addressed by the completion of activities. The LWA defines "test phase activities" to mean "the testing and experimentation activities to determine the suitability of the WIPP as a repository for the permanent isolation of transuranic waste." For the purposes of this Plan, "activity" means an integrated program of studies designed to provide specific information about a subsystem or component of the WIPP disposal system, or about events that may affect the disposal system.

The relationships of information needs and activities among the regulatory compliance programs are given in Table 2-1. Of the activities listed, site characteristics and repository design are complete; no studies related to these activities are ongoing. The studies being performed or that are planned to support the activities are listed in Table 2-2 (site characteristics and repository design activities are not listed).

2.3.2 Studies Not Involving TRU Mixed Waste

The majority of the studies planned for the test phase involve neither actual wastes nor simulated wastes. In many cases, these studies are continuations of studies that have been underway for a number of years. These studies are designed to provide necessary information about the disposal system, continuing the characterization of the natural barriers and analyzing and evaluating the engineered barriers. Information is also needed about waste interactions that are independent of the radioactive or hazardous nature of the wastes. The potential effects of inadvertent human intrusion must also be understood. Information from these studies is as important for demonstrating compliance as is the information from tests that involve wastes.

2.3.2.1 Studies to Characterize Natural Barriers

The investigations of natural barriers are directed at understanding the properties of two natural barriers that are expected to be principal contributors to waste isolation over the long term: the Salado Formation, which is the host rock for the WIPP, and the overlying Rustler Formation. In particular, the investigations will focus on understanding the movement of fluids into and out of the waste rooms and the transport of waste constituents through or past these barriers. This requires a detailed knowledge of the characteristics of the various rock formations, two-phase fluid flow, and the mechanisms and potentials for retarding the transport of waste constituents. These investigations are under way; they are extensions of geologic, hydrologic, and geochemical studies performed since the start of site characterization in 1975. The studies of natural barriers consist of laboratory experiments, modeling, and tests in the field.

The rock units above the Salado Formation have an important role in the performance of the WIPP disposal system: preventing or inhibiting the migration of radionuclides and gases released from the waste into the accessible environment. The scenarios that have been developed to predict long-term performance have indicated that one unit—a dolomite layer known as the Culebra Dolomite Member of the Rustler Formation—could provide a pathway to the accessible environment, in the event of inadvertent human intrusion (i.e., drilling in search of resources like oil or gas) into the repository. Predicting possible pathways and travel times for radionuclides in the Culebra to reach the accessible environment is one of the critical tasks of the performance assessment. These pathways and travel times strongly depend on the rates and directions of ground-water flow in the Culebra and other rock units above the Salado Formation over the time periods of regulatory concern. The other major controls on radionuclide transport to the accessible environment are the retardation factors for the radionuclides traveling through the Culebra. Several of the studies planned for the test phase are focused on those characteristics of the Culebra that would effect radionuclide transport through the Culebra.

Laboratory studies are being performed to investigate various properties of the Salado Formation that are important to long-term performance and must be adequately understood for performance assessment. These studies are designed to determine whether significant quantities of brine can flow into the waste disposal rooms from the Salado, if the Salado can store significant quantities of gas, and whether the Salado will provide a barrier to isolate radionuclides and hazardous constituents. Studies of transport in the Salado are focused on the anhydrite layers. Many of these studies are new

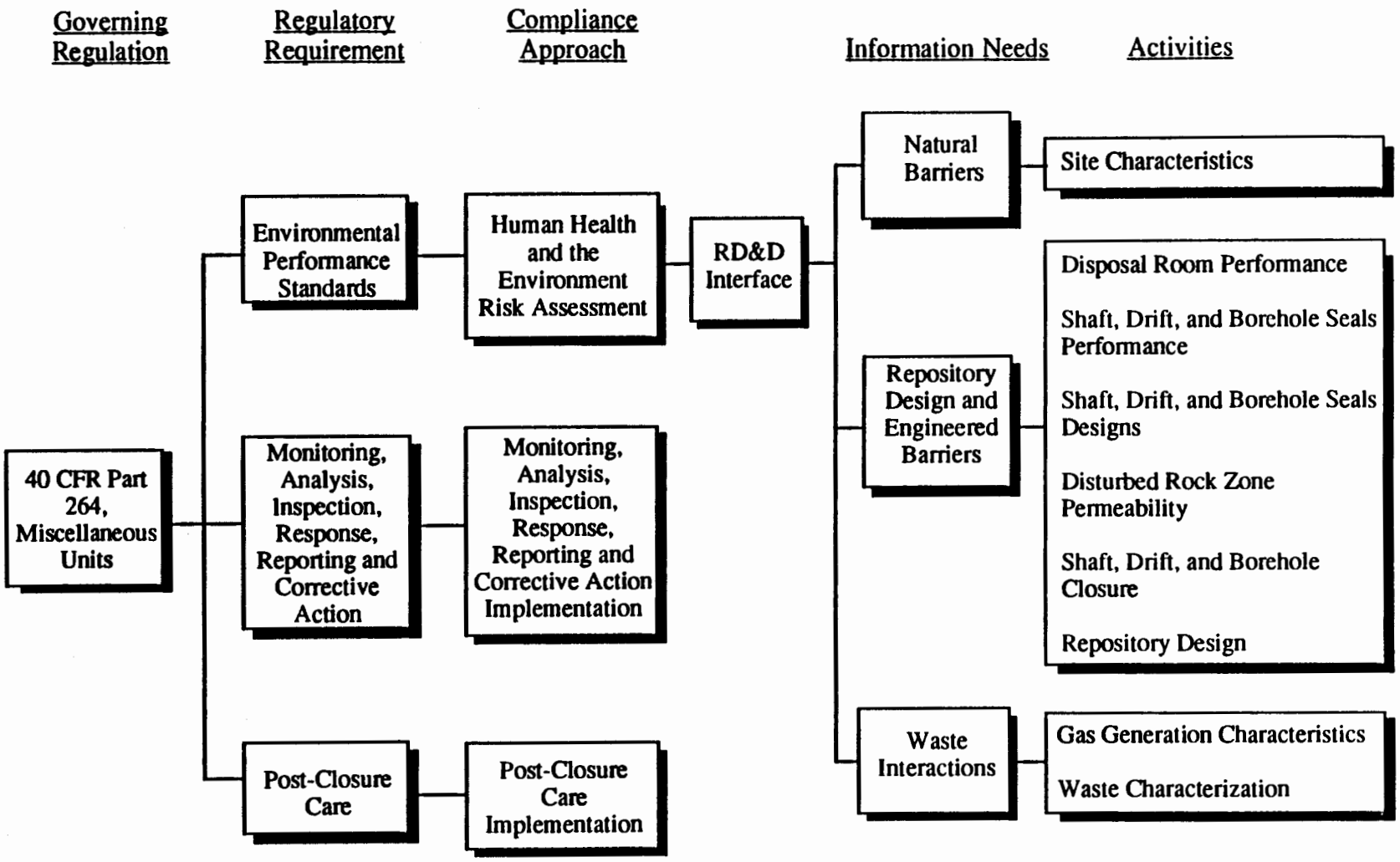


Figure 2-4. Short-Term 40 CFR 264, Subpart X Compliance Program Structure.

Table 2-1. Relationships of Information Needs, Activities, and Compliance Programs

Information Needs	Activities	Compliance Programs				
		40 CFR 191		40 CFR 268.6		40 CFR 264 Subpart X
		Undisturbed	Disturbed	Long-term	Short-term	
Natural Barriers	Non-Salado Hydrologic Properties		●			
	Non-Salado Transport		●			
	Salado Hydrologic Properties	●	●	●		
	Salado Transport	●	●	●		
	Site Characteristics	●	●	●	●	●
Repository Design and Engineered Barriers	Disposal Room Performance	●	●	●	●	●
	Shaft, Drift, and Borehole Seals Performance	●	●	●	●	●
	Shaft, Drift, and Borehole Seals Designs	●	●	●	●	●
	Disturbed Rock Zone Permeability	●	●	●	●	●
	Shaft, Drift, and Borehole Closure	●	●	●	●	●
	Repository Design	●	●	●	●	●
Waste Interactions	Gas Generation Characteristics	●	●	●	●	●
	Radionuclide Source Term in Disposal Room Brine	●	●			
	Waste Characterization	●	●	●	●	●
	RCRA Constituents Source Term in Disposal Room Brine and Gas			●		
Human Intrusion	Human Intrusion Modeling		●			
	Probability of Human Intrusion		●			
	Cuttings Release Parameters		●			

Table 2-2. Research, Development, and Design Program

Information Needs	Activities	Test Phase Studies	Chapter 5 Section
Natural Barriers	Non-Salado Hydrologic Properties	Core Studies of Non-Salado Rock Properties	5.1.1.1
		Regional-Scale Transport and Sensitivity Studies	5.1.1.2
		Model Development for the Non-Salado	5.1.1.3
		Field Testing and Data Interpretation for Non-Salado Hydrology	5.1.1.4
		Regional Geochemical Studies	5.1.1.5
		Data Base for Non-Salado Field Studies	5.1.1.6
		Validation and International Collaboration for Non-Salado Model	5.1.1.7
		Verification of Non-Salado Performance-Assessment Model	5.1.1.8
		Identifying Potential Underground Sources of Drinking Water	5.1.1.9
		Non-Salado Data Base for Performance Assessment	5.1.2.9
	Non-Salado Transport	Adsorption Studies for the Non-Salado	5.1.2.1
		Radionuclide Solubility and Speciation for the Non-Salado	5.1.2.2
		Brine Mixing and Radionuclide Coprecipitation for the Non-Salado	5.1.2.3
		Empirical Sorption Studies for the Non-Salado	5.1.2.4
		Column Experiments for the Non-Salado	5.1.2.5
		Long-Core Tracer Tests for the Non-Salado	5.1.2.6
		Colloid Characterization and Transport for the Non-Salado	5.1.2.7
		Test Design and Interpretation for the Non-Salado	5.1.2.8
		Non-Salado Data Base for Performance Assessment	5.1.2.9
		Sorbing/Retarding Tracer Tests for the Non-Salado	5.1.2.10
		Data Base for Non-Salado Laboratory Studies	5.1.2.11
		Non-Sorbing Tracer Tests for the Non-Salado	5.1.2.12
		Regional-Scale Transport and Sensitivity Studies	5.1.1.2
		Model Development for the Non-Salado	5.1.1.3
		Regional Geochemical Studies	5.1.1.5
		Data Base for Non-Salado Field Studies	5.1.1.6
		Validation and International Collaboration for Non-Salado Model	5.1.1.7
		Verification of Non-Salado Performance-Assessment Model	5.1.1.8

Table 2-2. Research, Development, and Design Program (Continued)

Information Needs	Activities	Test Phase Studies	Chapter 5 Section
Natural Barriers	Salado Hydrologic Properties	Salado Threshold Pressure	5.1.3.1
		Salado Relative Permeability	5.1.3.2
		Salado Permeability Versus Stress	5.1.3.3
		Salado Porosity	5.1.3.4
		Salado Brine Chemistry	5.1.3.5
		Data Base for Salado Laboratory Studies	5.1.3.6
		Repository-Scale Multiphase Modeling and Sensitivity Studies	5.1.3.7
		Model Development for the Salado	5.1.3.8
		Test Design and Interpretation for the Salado	5.1.3.9
		Validation and International Collaboration for Salado Model	5.1.3.10
		Salado Data Base for Performance Assessment	5.1.3.11
		Salado Far-Field Permeability Testing	5.1.3.12
		Small-Scale/Intermediate-Scale Brine-Inflow Experiments	5.1.3.13
		Large-Scale Brine-Inflow Experiments	5.1.3.14
		Threshold-Pressure Testing in Marker Bed 139	5.1.3.15
		Data Base for Salado Field Studies	5.1.3.16
		Benchmarking of Mechanistic and Performance-Assessment Models	5.1.3.17
		Hydrofracture Studies of the Anhydrite Beds	5.2.4.7
	Salado Transport	Gas Solubility in Salado Brines	5.1.4.1
		Retardation in the Salado	5.1.4.2
		Tracer and Transport Testing in the Salado	5.1.4.3
		RCRA Constituents Retardation in the Salado	5.1.4.4
		Salado Threshold Pressure	5.1.3.1
		Salado Relative Permeability	5.1.3.2
		Salado Permeability Versus Stress	5.1.3.3
		Salado Porosity	5.1.3.4
		Salado Brine Chemistry	5.1.3.5
		Repository-Scale Multiphase Modeling and Sensitivity Studies	5.1.3.7
		Model Development for the Salado	5.1.3.8
		Salado Data Base for Performance Assessment	5.1.3.11
		Salado Far-Field Permeability Testing	5.1.3.12
		Threshold-Pressure Testing of Marker Bed 139	5.1.3.15
		Data Base for Salado Field Studies	5.1.3.16
		Benchmarking of Mechanistic and Performance-Assessment Models	5.1.3.17
		Hydrofracture Studies of the Anhydrite Beds	5.2.4.7

Table 2-2. Research, Development, and Design Program (Continued)

Information Needs	Activities	Test Phase Studies	Chapter 5 Section
Repository Design and Engineered Barriers	Disposal Room Performance	Properties of Disposal-Room Backfill	5.2.1.1
		Mechanical and Permeability Properties of Waste	5.2.1.2
		Mechanical Model of Disposal-Room Backfill	5.2.1.3
		Model of Waste Mechanical Properties	5.2.1.4
		Disposal-Room Model and Data Base	5.2.1.5
		Model of Engineered Alternatives	5.2.1.6
		Tests of Simulated Disposal Rooms (Rooms T and J)	5.2.1.7
		Feasibility Analysis for Room-Scale Test	5.2.1.8
	Shaft, Drift, and Borehole Seals Performance	Development of Materials for Short-Term Seals	5.2.2.1
		Development of Materials for Crushed-Salt Seals	5.2.2.2
		Data Base for Seals Materials	5.2.2.3
		Model of Seals Components	5.2.2.4
		Sealing System Integration	5.2.2.5
		Small-Scale Tests of Seals Performance	5.2.2.6
		Large-Scale Testing of Seals	5.2.2.7
		Borehole Plugging Tests	5.2.2.8
	Shaft, Drift, and Borehole Seals Designs	Seal Design and System Model	5.2.3.1
		Model of Seals Components	5.2.2.4
		Sealing System Integration	5.2.2.5
		Small-Scale Tests of Seals Performance	5.2.2.6
		Large-Scale Testing of Seals	5.2.2.7
		Borehole Plugging Tests	5.2.2.8
		Study of Material and Fracture Properties	5.2.4.1
		Disturbed-Rock-Zone Mechanisms	5.2.4.2
		Kinetics of Fracture Healing in Salt	5.2.4.3
		Development of Constitutive Model of Fractures	5.2.5.4
		Development of Numerical Code	5.2.5.5
		Verification and Validation of Code	5.2.5.6
	Disturbed Rock Zone Permeability	Study of Material and Fracture Properties	5.2.4.1
		Disturbed-Rock-Zone Mechanisms	5.2.4.2
		Kinetics of Fracture Healing in Salt	5.2.4.3
		Mechanical Model of Excavation Effects in the Disturbed Rock Zone	5.2.4.4
		Characterization of the Disturbed Rock Zone	5.2.4.5
		Geophysics of the Disposal System	5.2.4.6
		Hydrofracture Studies of the Anhydrite Beds	5.2.4.7

Table 2-2. Research, Development, and Design Program (Concluded)

Information Needs	Activities	Test Phase Studies	Chapter 5 Section
Repository Design and Engineered Barriers	Shaft, Drift, and Borehole Closure	Distribution Functions for Creep Parameters	5.2.5.1
		Validation, Documentation, and QA for the Rock-Mechanics Data Base	5.2.5.2
		Development of Salt Constitutive Model	5.2.5.3
		Development of Fracture Constitutive Model	5.2.5.4
		Development of Numerical Code	5.2.5.5
		Verification and Validation of Code	5.2.5.6
		Performance of Air Intake Shaft	5.2.5.7
		Intermediate-Scale Borehole Test	5.2.5.8
		Panel Structural Test	5.2.5.9
		Test of Thermal and Structural Interactions	5.2.5.10
		Integration of Rock-Mechanics Studies	5.2.5.11
		Mine-Support-System Technology and Demonstrations	5.2.5.12
Waste Interactions	Gas Generation Characteristics	Model of Gas Generation	5.3.1.1
		Laboratory Studies of Gas Generation	5.3.1.2
		Gas-Generation Experiments (Bin Tests) with CH TRU Waste	5.3.1.3
	Radionuclide Source Term in Disposal Room Brine	Model of the Actinide Source Term	5.3.2.1
		Laboratory Studies of the Actinide Source Term	5.3.2.2
		Large-Scale Studies of the Actinide Source Term with CH TRU Waste	5.3.2.3
	Waste Characterization	Characterization of the Waste Inventory for the Compliance Source Terms	5.3.3.1
	RCRA Constituents Source Term in Disposal Room Brine and Gas	Hazardous-Organic-Constituents Degradation Rates and Reaction Products	5.3.4.1
		Characterization of VOC Transport out of Waste Containers	5.3.4.2
		Design of Alcove Test	5.3.4.3
		Design and Testing of Alcove Gas-Barrier, -Management, and -Sampling Systems	5.3.4.4
		Alcove Test Operations	5.3.4.5
		Characterization and Preparation of Alcove Waste	5.3.4.6
		Model of Gas Generation	5.3.1.1
		Laboratory Studies of Gas Generation	5.3.1.2
		Gas-Generation Experiments (Bin Tests) with CH TRU Waste	5.3.1.3
		Characterization of the Waste Inventory for the Compliance Source Terms	5.3.3.1
Human Intrusion	Human Intrusion Modeling	Culebra Desaturation Resulting from Human Intrusion	5.4.1.1
	Probability of Human Intrusion	Expert Panels (Probability of Human Intrusion vs. Time)	5.4.2.1
	Cuttings Release Parameters	Laboratory Studies of Drill Cuttings	5.4.3.1
		Model of Drill Cuttings	5.4.3.2

and are directed at collecting data for predicting what will happen to the gases evolved from the waste, including the potential and rate of gas migration through the host rock and the relative permeability of the Salado for brine inflow and gas outflow. Some studies will examine the effects of excavations on permeability and porosity.

An extensive series of site characterization studies have been performed at the WIPP site and the surrounding area, beginning in 1975. These studies have included investigations of site and regional geology and hydrology, as well as studies of biological and archeological resources. Geologic and hydrologic studies have included investigations of site and regional tectonics and seismicity, geochemistry, and lithologic suitability. Given the exhaustive range of these studies, the subsurface in the vicinity of the WIPP site is among the most highly characterized subsurface environments in the world. Site characterization studies are completed; none is ongoing. However, some data sets obtained through these studies continue to be subject to evaluation and analyses. The site characterization data base is an essential source of information about the natural barriers, and will continue to be examined during the test phase.

2.3.2.2 Studies Related to the Repository Design and Engineered Barriers

A critical component of performance assessment is the ability to simulate the likely long-term behavior of the waste and the WIPP repository, including the backfill that will be emplaced in all of the excavations (disposal rooms, access ways, drifts). Of special interest are several phenomena that may affect long-term performance: the closure of disposal rooms through the plastic flow of the surrounding salt (salt creep) and the consolidation of the backfill. To reduce uncertainties about the postclosure response, the DOE has planned a number of laboratory studies, modeling studies, and tests underground at the WIPP facility. Objectives include obtaining data needed for estimating the potential consequences of inadvertent human intrusion and data needed for selecting or designing seals and backfill.

Also needed for performance assessment is a disposal-room model that not only accounts for important processes like salt creep, the response of the backfill, the mechanical response of the waste, gas generation potentials and rates, and the rate of brine inflow, but also for interactions among these processes. This model will provide information on the porosities and permeabilities of the disposal rooms, and it will indicate which phenomena exert a significant effect on performance. Other studies include developing or refining models of backfill and waste behavior and gas generation.

The DOE is conducting an extensive program of laboratory, modeling, and field studies directed at collecting the data needed to design seals, to ensure that mine stability can be maintained during waste-emplacement operations, and to understand the mechanical behavior of the host rock during and after waste emplacement. The data and models of seal behavior and rock mechanics are important for performance assessment. The DOE is also developing models for analyzing the structural and creep response of seal and plug components, the consolidation of backfill, and the evolution of the disturbed-rock zone. The resulting computational models will be used to assess designs, develop design criteria, plan tests, and design experiments; models of seal components will also be integrated into system models for performance assessment.

In preparing the WIPP facility for decommissioning, underground accessways, panels, shafts, and boreholes will be sealed. The objective of the design work related to the sealing program is to provide validated, detailed designs of the seal components. Detailed designs are essential to provide assurance that the proposed seal components can be feasibly emplaced with sufficient quality control to ensure the needed performance. Demonstrations of the feasibility of constructing selected components are planned as part of the validation efforts.

An important requirement is understanding the behavior of the host rock, including salt creep; the stability of the underground excavations; the development and propagation of fractures; and the development of cracks in the disturbed-rock zone that occurs around excavations. These phenomena are important to long-term performance because they may affect the porosity of the seals. The DOE is conducting a comprehensive program of laboratory studies, modeling, and field studies in the WIPP underground to collect the needed information about the behavior of the host rock.

If the performance assessment indicates that the WIPP repository as currently designed with the existing waste forms will not meet the performance standards, engineered alternatives will be evaluated. Such alternatives might include modification of the waste form or waste containers, modification of backfill materials, or modification of the design of plugs and seals.

The repository design and as-built drawings form the basis for performance evaluations. Changes in the performance evaluations related to repository design would be likely only if substantial modifications were made in the construction of the remaining panels or if maintenance operations were to be extensively modified. No additional work in this area is believed necessary, except to ensure that construction and operations-related decisions remain consistent with the assumptions and data used in compliance evaluations and to ensure that any changes in design resulting from the decisions on compliance are evaluated and documented.

2.3.2.3 Studies to Characterize Waste Interactions

An understanding of the chemical and physical characteristics of the waste and anticipated interactions between wastes, waste containers, and the repository environment is needed to predict the performance of the planned repository. The radiological, chemical, and physical characteristics of the wastes to be used in tests are currently being established through extensive sampling and analysis programs. Laboratory and field studies and modeling programs are being pursued to gain better understanding of waste interactions that may contribute to the generation of gas, and leaching and dissolution of waste constituents, in the repository environment. Literature reviews and laboratory and field studies, as well as modeling programs, are being pursued to develop a better understanding of the concentrations of radionuclides and hazardous chemicals that may be expected to be present in the waste disposal rooms after closure. These studies will help to define the "source term" for performance assessment. In this sense, the source term refers to the types and concentrations of radioactive and hazardous constituents that will be released from the waste due to leaching and dissolution by brine, and that will be available to potentially migrate away from the waste-emplacement rooms.

The leaching and solubility of radionuclides in brine and hazardous chemicals in brine and gas is important because brine and gas are potential carriers. Studies are underway to evaluate the potential concentrations of radionuclides and hazardous chemicals in brine and gas under a variety of chemical conditions expected to occur in the repository.

Gas produced by the decomposition of organic components of the waste or corrosion of metals may contribute to the pressurization of the closed repository and create a force that may tend to drive hazardous materials away from the waste-emplacement rooms. A series of studies is being pursued to investigate gas-generating processes. These studies will include tests with TRU mixed waste (as described in Section 2.3.3) as well as tests with simulated waste. The gas generation model will be validated and refined by the results of these tests (see Section 2.3.3.2).

Waste characterization data are required to comply with regulatory programs regarding the management, transport, and disposal of TRU mixed waste. Information about the radionuclide

inventory and the inventory of regulated hazardous chemicals contained in the TRU mixed wastes is needed for the performance assessment. In addition, information regarding the chemical nature of the various waste matrices will be used to model chemical environments which may act to mobilize materials in the repository. Data obtained through waste characterization efforts will also allow the modeling of gas or liquid-generating mechanisms that may contribute to migration of materials from the repository.

2.3.2.4 Studies Related to Human Intrusion

EPA guidance for implementing the containment requirements of 40 CFR 191, Subpart B specify that the potential for inadvertent human intrusion into the repository be considered when calculating cumulative releases to the accessible environment. Studies are being pursued to develop greater confidence in predictions of the probability of inadvertent human intrusion events and estimates of the quantities of materials that might be released from the repository in the event that human intrusion occurs. This work will be of value to uncertainty analyses for the 40 CFR 268.6 compliance program, as well as for the 40 CFR 191, Subpart B program.

Expert panels consisting of individuals with diverse backgrounds have been organized to develop quantitative judgements regarding the probabilities of human intrusion. Probability estimates are incorporated into the performance-assessment process. Recommendations from these groups will be applied to the design of permanent markers and record keeping systems. Expert panels are also planned to address other aspects of performance assessment not amenable to direct experimentation.

Inadvertent human intrusion most likely will be the result of the future loss of knowledge of the disposal system, with future societies drilling through the repository in search of resources such as oil or gas. If this occurs, waste materials could become entrained in drill cuttings and brought to the surface through the drill hole. To predict the potential consequences of this, it is necessary to evaluate the amount of cuttings that would become entrained in drilling fluid and the behavior of the contaminated fluids. Studies are being pursued to quantify the relevant processes. The results of this work are being incorporated into simulation models to predict the consequences of the human intrusion event.

2.3.3 Studies Involving TRU Mixed Waste

Although the studies involving TRU mixed waste are a small part of the overall test phase activities, some of these studies initiate the receipt of waste at the WIPP facility. The studies involving TRU mixed waste are designed to provide confirmation that performance models are adequate and that potential synergistic or antagonistic effects are understood. Although some of the wastes proposed to be used in tests in the WIPP underground may not be mixed with hazardous chemicals, all test wastes will be managed as TRU mixed waste.

The DOE is planning experiments and tests with both simulated waste and TRU mixed waste, to be conducted underground at the WIPP, at the Los Alamos National Laboratory, and at the Idaho National Engineering Laboratory. These studies are part of the gas generation program and the source-term program, which are designed to meet the following needs for performance-assessment modeling: (1) a gas generation model that predicts the rate at which gas will be generated by the TRU mixed waste in a disposal room; (2) an actinide source-term model that predicts the concentrations of actinides that could be dissolved or suspended in brine; and (3) information on quantities and concentrations of volatile organic compounds (VOCs) that may be released from waste containers. In addition, the relationship between hazardous waste constituents and the gas and brine will be investigated.

Models of gas generation and concentration will be developed from data provided by laboratory experiments; the adequacy of modeling predictions will be assessed by comparisons with the results of tests with TRU mixed waste (bin tests) performed underground at the WIPP. The actinide source-term model will be based on laboratory experiments; the adequacy of this model will be assessed by comparisons with the results of actinide source-term tests performed at the Los Alamos National Laboratory. The quantities and concentrations of VOCs that will be emitted from waste containers after emplacement in the WIPP disposal area will be predicted from results of VOC sampling studies performed at the Idaho National Engineering Laboratory and from other waste characterization work. The adequacy of these predictions will be assessed by comparisons with the results of larger scale tests with TRU mixed waste conducted underground at the WIPP in a specially designed room called an "alcove." A detailed discussion of the gas generation and source-term programs is given in the TNAD (DOE, 1992a).

Studies to be conducted with radioactive wastes at the WIPP include bin tests and alcove tests. The EPA will review the activities presented in this Plan to determine if they will provide information that is directly relevant to a certification of compliance with the final disposal regulations, or to compliance with the RCRA (see Section 1.2). The DOE believes that both the bin tests and the alcove tests are directly relevant. The bin tests will improve the degree of confidence that model predictions of gas generation will not be exceeded by gas generation from actual wastes under extremes of possible environmental conditions. The alcove test is designed to provide evidence of the disposal-room-scale inventory of hazardous gaseous materials that are to be considered in the modeling of hazardous material movement during disposal operations and in various safety analyses.

These tests results will establish whether or not gases or gas production rates not predicted by the gas generation model occur, and will establish evidence of the concentrations of VOCs that will be present during waste disposal (i.e., the "short term" VOC source term). If the TRU mixed-waste test results are bounded by the gas-generation model predictions and the RCRA VOC source term predictions, this will enhance confidence that the disposal system behavior will not result in consequences beyond those predicted by performance assessments and waste mobility modeling. If the results of the bin and alcove tests should exceed the predictions, then phenomena that are not adequately understood are involved and further investigation will be necessary to describe them and incorporate the relevant process(es) into the analyses and modeling. Either result will lead to improved confidence in the ability of the analyses and models to bound gas generation and the RCRA source term.

2.3.3.1 Bin Tests to Characterize Gas Generation

Transuranic mixed waste contains various materials from which gases can evolve. Performance-assessment analyses simulate mechanisms that generate gas over time. The information on these mechanisms should be obtained under potentially realistic repository conditions; most of these tests must be conducted in an oxygen-free environment such as that expected to occur in the planned repository as time passes. The DOE will conduct bin tests with contact-handled TRU mixed waste in the WIPP underground. These tests will allow the DOE to study gas generation mechanisms and rates on a larger scale and under more realistic conditions than that possible in the laboratory. They will also provide an opportunity to observe waste interactions, both synergistic and antagonistic, that may not be observable in the smaller-scale laboratory tests that do not use TRU mixed waste. The results of the bin tests will be used to evaluate the suitability of the gas generation models used in performance assessments.

The waste for the tests are currently planned to come from the Rocky Flats Plant and the Idaho National Engineering Laboratory. Some of the waste will have a high organic content; this waste

includes combustible solidified organic materials, organic filters, leaded rubber, organic materials solidified in cement, and mixed organic wastes. Wastes with a low organic content will also be used; this waste consists of graphite, equipment, metals, glass, inorganic solids, and pyrochemical salts. Inorganic sludges and inorganic particulate waste solidified in cement will also be tested.

Each container of waste to be used in the bin program will be characterized to determine its content. The *Waste Characterization Program Plan* (DOE, 1992c) describes in detail how the waste will be characterized. After characterization, the waste, without its container, will be transferred to a metal bin. Each bin will be overpacked and shipped to the WIPP site in specially designed shipping containers called TRUPACT-IIs. These containers have been demonstrated to provide safe transportation for radioactive materials under both normal and accident conditions and have been approved by the U.S. Nuclear Regulatory Commission (NRC, 1989).

The bin tests will be conducted in a test room in the waste-disposal area (see Figure 1-4). As described in the *Waste Retrieval Plan for the Waste Isolation Pilot Plant* (DOE, 1993a), all of the bins used in the WIPP underground tests will be fully retrievable, and, as required by the LWA, the DOE will perform annual demonstrations of retrieval and make an annual determination of retrievability.

The complexity of the bin tests ranges from simple tests with only a few waste materials to complex tests that intentionally combine as many individual waste materials as possible. The simple tests will be designed to provide information about gas generation primarily from metal corrosion, microbial degradation, and radiolysis. The complex tests will evaluate the adequacy of model predictions of interactions between waste materials that affect gas generation; they will allow incorporation of synergistic and antagonistic interactions among these gas generation processes.

In some bins, the inside humidity will be raised to approximately 70 percent relative humidity. The objective is to simulate the conditions that will exist in the disposal rooms after the room has been filled with waste, sealed, and the ventilation system shut off. These are called "humid bins." Enough brine will be added to other bins to completely inundate the waste, and therefore these bins are called "inundated bins." The brine will be added to the bins at the WIPP facility.

Simulated waste materials will be emplaced in the same type of bins (i.e., dry, humid, and inundated conditions in both low and high pressure designs). The simulated waste tests will help to assure that all safety and health considerations have been addressed before the tests with TRU mixed waste in bins are started. This work will also provide useful information for designing test equipment.

The bin-test program consists of three tiers of experiments: (1) specifically planned tests, (2) conditionally planned tests, and (3) contingency tests. The specifically planned tests are those individually identified to reduce uncertainty and increase confidence in the ability to predict gas generation rates and species. The DOE plans to conduct these tests with 19 bins of TRU mixed waste. The conditionally planned tests are tests that will be conducted if the results from the specifically planned tests have not adequately reduced the level of uncertainty about gas generation. If these tests are needed, they will be conducted with up to 25 additional bins of TRU mixed waste.

Contingency tests may be conducted if unexpected results are obtained from planned tests, or if requests for additional tests are made by regulatory or oversight bodies, or if further investigations of specific engineered modifications of the waste form are needed to enhance performance and facilitate the demonstration of compliance. How many bins would be used in contingency tests cannot be predicted now, although the WIPP Land Withdrawal Act imposes an upper limit on the amount of

waste that may be emplaced during the test phase. This limit is 0.5 percent of the planned repository's maximum capacity.

Information which describes the total gas potential and gas generation rates associated with the degradation of TRU wastes is relevant to the development of and evaluation of a predictive model for use in WIPP compliance analyses. The various individual mechanisms are being examined in separate laboratory studies. The information from these experiments is the basis for development of the gas generation model. The bin tests will allow the examination of combinations of gas generating mechanisms and the net effects of such combinations. The model will be utilized to predict the various gas species which would be generated by each bin over time during the test period. The actual gas generated (species and concentrations) will be compared with model predictions. These comparisons will serve to evaluate the predictive capability of the gas generation model, provide feedback for further laboratory studies and model revisions if necessary, and provide evidence that the final gas generation model will predict conservatively. The bin tests are designed to provide a mechanism for DOE to assure that the gas generation model reflects the effects of specific waste types and site conditions and that the model has been confirmed with actual waste measurements.

2.3.3.2 Alcove Test(s) to Characterize Disposal-Room Gas Conditions

The DOE has determined that information on the RCRA source term is relevant to demonstrating compliance with the two RCRA standards addressed in this Plan. This determination is based on the regulatory requirements, on the need to design and test engineered barriers to limit VOC movement, and the need to design and test monitoring systems to assure that regulatory performance standards are being met.

To this end, the DOE plans to conduct, in the WIPP underground, a test with adequate quantities of waste to simulate disposal room conditions. This test will be conducted in a specially excavated area, the test alcove (see Figure 1-4). The quantity of waste used in this test will be approximately equivalent to 1050 drums. The plan currently calls for the emplacement of waste in a single alcove; the waste filled alcove will not be backfilled. An additional alcove test using solidified sludge wastes may also be performed as a contingency, if sufficient quantities of solidified sludge wastes are not available in time for the first alcove.

Data will be collected on the amounts and types of volatile organic compounds and other gases that will be released into a disposal room. The objective is to reduce the uncertainties associated with data collected from drum sampling. The alcove test will allow the DOE to measure in a macroscopic manner the overall emissions of gases from an array of drums having various sealing and gas filtration configurations. Information about gas releases, including the rate at which gases are released from containers and the time over which releases can occur, is needed to determine whether working conditions will be safe in the vicinity of the filled disposal rooms during waste emplacement. Information is also needed about the concentrations of gases in air that could potentially be released to the environment through the ventilation system or that could become a source term for the no-migration determination for the disposal phase. In addition, information regarding interactions between the gases and the repository environment is needed.

The alcove test(s) will use TRU mixed waste contained in 55-gallon steel drums. The drums will contain only unmodified, contact-handled TRU mixed waste, without additives or brine. The test will replicate, as closely as possible, the environment expected to be present in the WIPP during waste-emplacement operations.

Before an alcove test can be started, a gas barrier must be installed in the entrance to the alcove to seal the alcove, minimizing the escape of gases from the alcove. In addition, a gas sampling system must be designed, fabricated and installed that will allow the sampling and measurement of the types and amounts of gases being released into the alcove headspace over time.

After an alcove has been filled and sealed, the relative humidity of the alcove will increase to approximately 70 percent. This moisture will increase gas production from corroding metals and biodegrading cellulosic materials. In addition, the radioactive material in the waste will cause the generation of gas through radiolysis of water. The accumulation of gases from degradation mechanisms may force volatile organic gases through inner layers of confinement within the waste containers, or through drum seals and/or drum filters. Understanding the potential for flammable organic gases to escape the drums will allow analysts and regulators to better assess the appropriateness of planned disposal room operations and seal designs.

2.3.3.3 Large-Scale Tests to Characterize the Actinide Source Term

Actinide source-term tests with TRU mixed waste will be conducted to measure the concentrations in brine of five radionuclides in the actinide series. The tests will attempt to determine whether and how interactions among brine, waste, and backfill additives affect the speciation, solubilities, sorption properties, and colloid formation of these radionuclides over time. The wastes will be spiked with the desired radionuclides to ensure that their concentrations in the brine will not be limited by inventory. Currently, 15 drum-scale and 39 liter-scale tests are planned. Both the tests and the analysis of the brines will be performed at the Los Alamos National Laboratory. These tests will continue until radionuclide concentrations stabilize or until the data collected are deemed sufficient for a source-term model for performance assessment.

2.3.3.4 Laboratory Tests to Characterize VOC Transport out of Waste Drums

A model is being developed to predict the concentrations of VOCs throughout a waste drum and to evaluate whether a drum headspace sample is representative of the entire void space in a waste drum. Model results will be compared to data collected from drums containing simulated and actual TRU mixed waste. The model development is being supported by a series of laboratory-scale experiments designed to study VOC transport mechanisms in drums containing either simulated or actual waste and to provide adequate data to develop and test the model. This work includes studies of the diffusivity and permeability of some pure VOCs and some mixtures of VOCs through polyethylene. The diffusion of VOCs from sealed polyethylene bottles is also being investigated. In addition, the VOC-adsorption capacity and transport properties of carbon composite filters normally used on waste drums are being measured. This information will be used to predict the quantities of VOCs that will be emitted from waste containers, once they are emplaced in the WIPP underground.

Chapter 3

Compliance Program for the Final Disposal Regulations

3. COMPLIANCE PROGRAM FOR THE FINAL DISPOSAL REGULATIONS

The Land Withdrawal Act requires that before beginning waste disposal in the WIPP the DOE must demonstrate compliance with the final disposal regulations promulgated by the EPA in 40 CFR Part 191, Subparts B and C for the disposal of transuranic waste, and the EPA must certify that the WIPP is in compliance. This chapter describes the DOE's plans for assessing the long-term performance of the WIPP to demonstrate compliance with the disposal regulations. Performance assessment is an iterative technique developed especially for predicting the long-term behavior of geologic repositories. Information developed during the test phase is necessary to complete the performance assessment.

3.1 COMPLIANCE APPROACH FOR THE LONG-TERM PERFORMANCE REQUIREMENTS OF 40 CFR 191, SUBPARTS B AND C

This section describes the compliance approach illustrated in Figure 2-1. During the test phase, the performance-assessment process will be conducted in biennial cycles, using the data increasingly available about the disposal system and the more refined models to predict disposal-system performance with increasing confidence. In each cycle, data from the test program will be used to update scenarios and update or validate models, and the models will be exercised to provide a "snapshot" of predicted performance. If at the end of any cycle the results demonstrate, at a sufficient level of confidence, that compliance can be achieved, and the models and data are adequate, then the DOE will begin the decision process for disposal. If the level of confidence is insufficient, testing will continue and another cycle of analyses will begin. Periodic reports on the results of the performance assessment will be prepared and, as required by the LWA, submitted to the State of New Mexico, the EPA, the NAS, and the EEG for review and comment.

The performance-assessment process will be ready for the demonstration of regulatory compliance when:

- The complete set of scenarios with significant probabilities of occurrence has been defined;
- The compliance-assessment system is considered adequate and is adequately documented to allow repetitions or modifications of each simulation;
- The data sets are considered adequate and the computational models and systems of models have been validated to the extent necessary; and
- The final analyses are complete, and a peer-review process has affirmed that the analyses are adequate.

The performance-assessment process serves several functions. In addition to predicting performance, it provides guidance to the test program, including specifications of priorities for proceeding with testing to satisfy information needs. By evaluating the behavior of the waste, the performance assessment will also determine whether any changes in the form of the waste or the waste containers are necessary. And if changes in some waste forms are deemed necessary, the performance assessment will identify the types of changes that are most likely to contribute to compliance. Engineered modifications of the planned WIPP repository may also be evaluated if it seems that they could be required to achieve compliance. Such changes would require engineering trade-off studies.

For each of the quantitative requirements in the final disposal regulations, the determination of reasonable expectation will be based on (1) quantitative analyses as specified in the requirement and (2) qualitative judgment (degree of confidence) derived from a formal review process. A flow chart that depicts these processes is given in Figure 3-1.

The quantitative analyses are the numerical predictions of repository performance required by the EPA to meet the requirements of the final disposal regulations. While the quantitative analyses are critical in demonstrating compliance, qualitative review of the quantitative results may be equally important. The EPA provided specific guidance for this, stating that "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 (EPA, 1985c)." Thus, how the implementing agency (i.e., the DOE in the case of the WIPP) will apply "qualitative judgment" in evaluating whether a reasonable expectation of compliance exists is important.

A formal review process is necessary for arriving at a reasonable expectation based on the degree of confidence in the repository design and engineered barriers, the data, the scenarios and associated probabilities, and the performance measures. This process will be established and overseen by the DOE, independently of the research and analysis processes. The evidence and conclusions supporting various elements of the analysis will be formally reviewed and documented by peers of the researchers and analysts; the peer reviewers will be from organizations external to the WIPP Project, shown in Figure 3-1 as "external peer review." These reviews will take place as the understanding of the disposal system and the performance-assessment method evolve through each biennial preliminary assessment of compliance. The documentation of the review will include recommendations about the status of the understanding of the disposal system and its performance. This documentation will become part of the administrative record, along with the technical reports and information and quality-assurance files considered in the review. Once the final assessments have been completed, a qualitative review of the administrative record will provide the basis for deciding whether there is a reasonable expectation of compliance. If a reasonable expectation is found to exist, an application for certification of compliance will be prepared for submittal to the EPA, and other relevant documents will be updated to reflect the performance-assessment results (e.g., DOE, 1990a).

3.1.1 Performance Assessment

Mathematical modeling, based on and supported by representative field and laboratory test data and expert judgment, is the method selected for assessing repository performance. The major elements of the WIPP performance-assessment process are (1) the characterization of the disposal system and the development of the modeling system, (2) scenario construction and probability assignment, (3) analysis of consequences, (4) uncertainty analysis, and (5) sensitivity analyses. Each of these elements and its current status are briefly described below (see Figure 3-1); more-detailed discussions are given in the sections that follow.

The first element listed above is needed to provide a thorough understanding of the disposal system and the radionuclide source term. Without this understanding, the performance of the disposal system cannot be assessed.

Scenarios describing both undisturbed and disturbed performance have been constructed and screened and are reevaluated for each performance-assessment cycle as additional information becomes available. Scenario probabilities are assigned. Human intrusion has been shown to be the dominant disturbed condition, and efforts to characterize why and how often future societies might inadvertently intrude are nearing completion. Plans for satisfying the assurance requirements for institutional control contribute to determining probabilities for human intrusion scenarios.

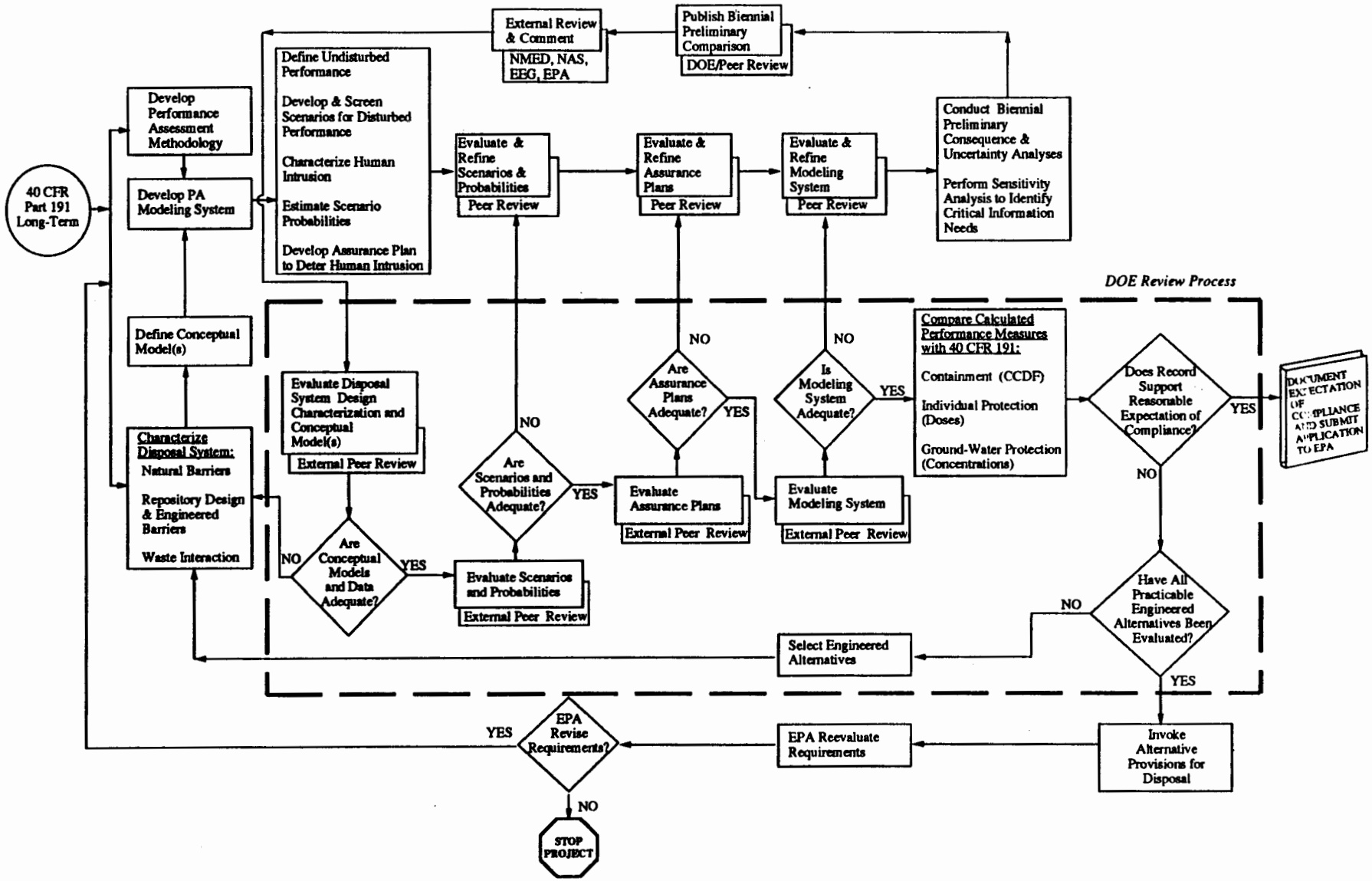


Figure 3-1. Performance-Assessment Approach for Disposal Regulations Compliance Program. The DOE review process is highlighted.

Scenarios and the associated probabilities are being reviewed and refined in the iterative process. As more is learned about the uncertainties associated with radionuclide containment within the disposal system, the plans for meeting the assurance requirements can be refined to complement the capabilities of the disposal system.

The modeling system is continually evaluated and refined as additional knowledge about the disposal system becomes available, and as new techniques for simulating physical and chemical processes are developed. The data base is continually updated except while calculations are underway. The LWA requires biennial performance assessments. For each cycle, preliminary consequence and uncertainty analyses require several months to complete. Once the uncertainty analyses have been completed, sensitivity analyses are performed to identify critical information needs.

A biennial report (see, for example, SNL, 1991), required by the LWA (Section 6(d)), is prepared, peer reviewed, and published. External review of the reports published on the preliminary assessments performed to date has been provided by the NMED and the EEG, who have commented on technical aspects of the analyses. Responses to their comments have been published as an appendix to the subsequent report. The LWA stipulates that the State, the EEG, the EPA, and the NAS shall have an opportunity to review and comment on the biennial report.

At this point in the process, the state of knowledge about the disposal system and the completeness and adequacy of the conceptual models of the system are evaluated. If critical information needs still exist, the cycle repeats. Later in the test phase, all the conceptual model components will be included in a series of computational models. During the subsequent years, appropriate sensitivity analyses will be completed to highlight important parameters and subsystems and the adequacy of these will be assessed. When sufficient robustness of the performance-assessment process and system has evolved, the final performance assessment will be completed.

The process to this point (see Figure 3-1) constitutes the analytical and iterative part of performance assessment. The other part is the DOE review process, described below, that will lead to a decision on whether there is a reasonable expectation of compliance.

If no new critical information needs are identified by the sensitivity analyses and the disposal-system characterization activities, and the conceptual models allow examination of all important plausible processes within the disposal system, and the performance-assessment process is sufficiently robust, external peer review will indicate that the final review should begin. Although the diagram in Figure 3-1 indicates a sequential process, DOE's review of the assessment will proceed in parallel with the assessment process. Formal, documented, quantitative reviews of the assessment and its bases will take place as the assessment evolves. The performance-assessment process is currently approaching adequate maturity for formal iterative reviews to be initiated. The final review would be a qualitative review of the administrative record to determine whether the elements of the assessment and the calculated performance measures are adequate to support a finding of reasonable expectation of compliance with each requirement.

Scenarios and probabilities, and the bases for their selection will be reviewed. If the scenarios and their probabilities are adequate and defensibly documented, the review will proceed to evaluate the assurance plans. The relationship between the plans for developing active and passive institutional controls and the human intrusion-scenario probabilities will be examined. Other assurance requirements that affect the results of the performance assessment will be reviewed, including natural and engineered barriers and the potential for resource extraction or exploration. Guidance for monitoring the disposal system after decommissioning may be developed from the results of the

undisturbed-performance predictions. Finally the adequacy of the modeling system, including the data base and supporting quality-control and quality-assurance documentation, will be examined.

The final calculated performance measures will be compared against the EPA requirements. The record comprises this comparison, the results of all the quantitative and qualitative reviews, and the supporting technical documentation. If the record is found to support a reasonable expectation of compliance, the performance assessment for initiating disposal operations is complete and can be documented. If the record does not support a reasonable expectation of compliance, effects on performance of the engineered alternatives (DOE, 1991b) will be evaluated. If the record clearly indicates that the disposal system provides good isolation, but the WIPP cannot reasonably be shown to comply with any of the requirements, the Alternative Provisions for Disposal contained in 40 CFR 191 will be invoked as provided for by the EPA (EPA, 1985c, 1993).

All data, models, and analytical processes will be qualified and documented according to established quality-assurance procedures. Throughout the process of developing information useful for performance assessment, transformations and assumptions that have been applied will be traceable and verifiable. The information used in the performance-assessment models will have traceable, verifiable records that satisfy quality-assurance requirements.

Preliminary performance assessments are being conducted to improve the process and its implementation prior to a final performance assessment. This final performance assessment will be compared with the disposal regulations as part of the decision process of whether to proceed with the disposal phase. Additional performance assessments will subsequently be performed to comply with requirements in section 8 of the LWA for periodic recertification of continued compliance with the final disposal regulations. The performance assessment will address the requirements in the regulations and adequately document the process and the findings. Coordination with the regulatory and institutional framework provides guidance for the performance assessment. The review process for the performance assessments provides an independent evaluation of the adequacy of the rationale for using a particular approach, the defensibility of the results, and of the adequacy of the documentation of the performance-assessment system.

The sections that follow give more detailed descriptions of the components of performance-assessment scenarios; models; expert judgment; uncertainty analysis; performance measures for the containment, individual protection, and ground-water protection requirements; and sensitivity analysis. Then interfaces with research, development, and design activities are discussed. A bibliography for the WIPP performance assessment, including published reports and reports in preparation, is provided in Appendix B to this Plan.

3.1.1.1 Scenarios

Scenarios are sets of naturally occurring and man-induced events and processes that represent realistic future states of the disposal system. "Events" are phenomena that occur instantaneously or within a relatively short time interval. "Processes" are phenomena that occur over a significant portion of the 10,000-year period of regulatory concern. The response of the disposal system to scenarios is simulated in performance-assessment analyses to predict the migration of radionuclides within the system and their release to the accessible environment.

Scenario development is accomplished by combining events and processes that could affect the performance of the disposal system. Both the scenarios and probabilities assigned to them will be adjusted for cyclic assessments as new information is available and as review comments dictate. Probabilities of human intrusion scenarios will be based on judgments elicited from experts on future

intrusion and marker development; they will account for inadvertent human intrusion and the potential effects of markers, protective barriers, and records in deterring intrusion. As each cycle of performance assessment is documented, previous review comments on scenarios (construction, assignment of probabilities, and approach to including uncertainty) will be addressed. Continued evaluation of scenarios and their probabilities is necessary to reflect improved understanding of possible disruptive events and processes, if any are identified.

Four criteria are being used in screening events and processes for evaluation in performance assessments: (1) physical reasonableness, an exclusionary criterion that requires a logical deduction based on available data and information and uses expert judgment to evaluate events and processes for which quantitative estimates of probability are not feasible or not appropriate; (2) probability of occurrence, which is based on a mathematical analysis of data or on expert judgment; (3) consequence, which results from the escape and transport of radionuclides away from the repository-and-shaft system; and (4) severity of human intrusion events, as limited by the EPA's guidance to the disposal regulations.

Although human intrusion is not mentioned in 191.13 or in the associated definitions, it is indirectly included because the EPA specifically excluded it from the definition of "undisturbed performance." In the guidance, the EPA identified human intrusion as an event that must be evaluated for 40 CFR 191.13. However, the guidance and the supplemental information published in 1985 with the rule limit human intrusion to nothing more severe than inadvertent, intermittent drilling into the repository during exploration for resources. Deliberate intrusions are excluded by the guidance. The EPA believes that only realistic possibilities for human intrusion that may be mitigated by design, site selection, and passive institutional controls need be considered. Additionally, the EPA assumes that passive institutional controls should reduce the chance of inadvertent intrusion compared to the likelihood if no markers and records were in place. In particular, as long as passive institutional controls endure and are understood, the guidance states they can be assumed to deter systematic or persistent exploitation of the disposal site, and furthermore, can reduce the likelihood of inadvertent, intermittent human intrusion (EPA, 1985c). Information needed for evaluating potential human intrusions is discussed in Section 3.2.4.

Calculations of the performance measures defined by the EPA require scenario analyses. Undisturbed performance is described by a scenario that contains all natural events and processes that are certain to occur. The undisturbed scenario is the basis for additional scenarios that project disturbance of the disposal system.

3.1.1.2 Models

A conceptual model in performance assessment is a set of qualitative descriptions that defines a system or subsystem for a given purpose. At a minimum, these descriptions concern the geometry and dimensionality of the system, the initial and boundary conditions, time dependence, and the nature of the relevant physical and chemical processes. The descriptions should be consistent with one another and with existing information within the context of the given purpose. Alternative conceptual models are alternative sets of descriptions that describe the same system for the same purpose, where each set is consistent with the existing information. Conceptual model uncertainty is the lack of knowledge about the system resulting from having limited information available to support or refute alternative conceptual models.

A mathematical model is the mathematical representation of a conceptual model (e.g., as coupled algebraic, differential, or integral equations that approximate the physical processes in a specified

domain of the conceptual model). The computational model implements the mathematical model. The computational model is often called a "computer code" or "computer model."

The performance assessments for the WIPP use computational models in a modular calculational system managed by a computerized executive package referred to as the "Compliance Assessment Methodology Controller" (CAMCON). This approach is sufficiently flexible to accommodate data and models representative of alternative conceptual models, alternative engineered waste forms, repository design changes, and changes in analytical techniques as new information warrants. General descriptions of performance-assessment modeling are given in this section, including models for hydrology, contaminant transport, repository and shaft systems, exposure and pathways and consequence analysis. The performance-assessment computational system for human intrusion scenarios as modeled in the 1991 preliminary performance assessment is illustrated in Figure 3-2.

Modeling and Analysis

In assessing the compliance of the WIPP with the disposal regulations, computational models that allow simulation of the impact of various events and processes on the disposal system will be developed or adapted, applied, and evaluated. These model regional and local ground-water flow in the Culebra Dolomite Member of the Rustler Formation; contaminant transport both in the planned repository and in the Culebra dolomite; the processes within the disposal room, the seals, and the surrounding Salado Formation; and releases of radionuclides that may occur following human intrusion. The continuing development of the models is necessary to incorporate changes in the conceptual models, to include additional parameters, and to improve operating systems. The computational model linkages and data flow for the consequence analyses are managed by CAMCON. Scenarios, and their probabilities, developed from combinations of events and processes that could affect the disposal system, drive the modeling.

The 1990 and 1991 performance-assessment calculations and related sensitivity analyses were based primarily on a single conceptual model for the engineered and natural barrier systems. Alternative conceptual models not inconsistent with existing information surely exist and must therefore be considered. The existence of alternative conceptual models contributes to the overall uncertainty but has not been thoroughly investigated. Approaches to identifying alternative conceptual models are contained in all of the technical program elements. All important conceptual models will be included in the computational system.

Hydrologic modeling of regional and local ground-water flow is the basis for calculating radionuclide transport in the Culebra dolomite. Calculations of ground-water flow will incorporate the uncertainty resulting from geologic and hydrologic parameters. The objectives of this work include developing and implementing geostatistical methods of incorporating uncertainty in the Culebra transmissivity fields and other parameters, examination of the effects of varying model recharge to reflect climatic change and vertical leakage, development of a three-dimensional computational model, and identification and incorporation of alternative conceptual models. This work is supported by the studies described under Section 3.2.1.1.

Contaminant-transport modeling for the repository environment is separate from that for the Culebra. Within the repository, radionuclide transport occurs in the liquid phase of a two-phase (gas and brine) fluid-flow system. Analyses of engineered alternatives will consider backfills other than salt and other waste forms as needed. Radionuclide concentrations in brine have been assumed to be controlled by solubility limits; preliminary solubility distributions have been estimated by an expert panel as have retardation factors in the Culebra. Solubility distributions and retardation factors will

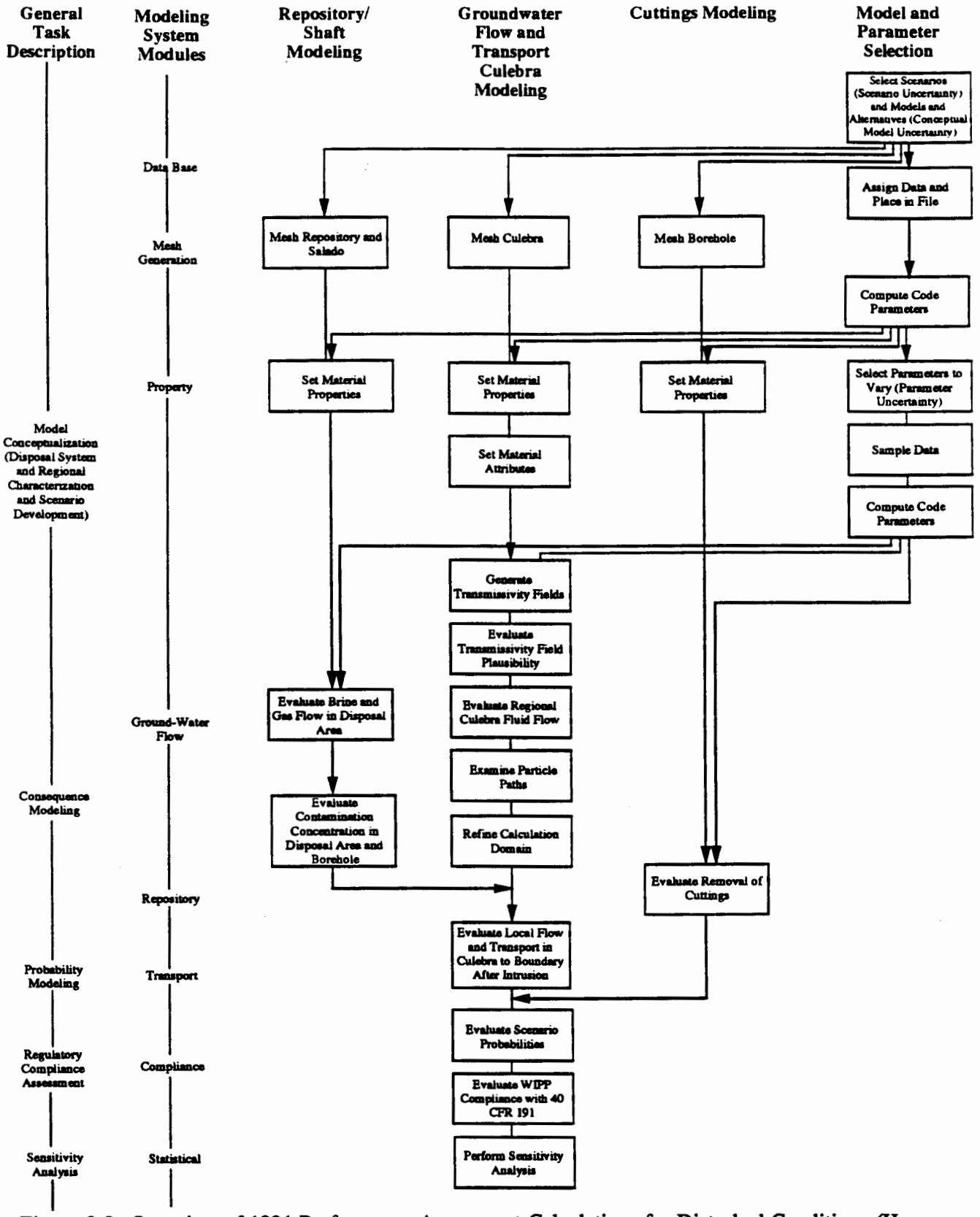


Figure 3-2. Overview of 1991 Performance-Assessment Calculations for Disturbed Conditions (Human Intrusion) (after SNL, 1991).

be replaced by measured values when available. Transport in the Culebra is modeled for double- or single-porosity, fractured rock. Uncertainties in the model used for Culebra flow will directly affect transport simulations. Retardation factors in the Culebra are uncertain. Preliminary uncertainty and sensitivity analyses have shown retardation to be important. Distributions of retardation factors were developed by an expert panel for the 1991 assessment, so that sensitivity of the system performance could be evaluated. The State of New Mexico has specified in the Consultation and Cooperation Agreement (DOE and State of New Mexico, 1981) that the DOE is to demonstrate experimentally the actual range of retardation factors to be expected in the Culebra, unless these values are assumed to be zero. This work is supported by the activities described in Sections 3.2.1.2, 3.2.1.4, and 3.2.2.1.

The transport of particulate waste up a borehole during human intrusion is modeled by calculating the amount of waste removed both as direct cuttings and by erosion of the borehole caused by the circulating drilling fluid. The amount of waste removed by other processes during drilling into a waste panel containing waste-generated gas is still unknown. Scoping calculations will be performed, and these processes will be included in future assessments. This work is supported by the Cuttings Release Parameters activity (Section 3.2.4.3).

The modeling of the repository/shaft system for performance assessment includes the modeling of processes within the disposal area, the seals, and the surrounding Salado Formation (including MB 138 and MB 139, anhydrite layers A and B, intact halite, and disturbed-rock zones). Specifically, the work includes the development and verification of performance-assessment models for gas generation, two-phase (brine and gas) Darcy flow, salt creep, and anhydrite fracturing. For the 1991 calculations, two-phase flow in the undisturbed repository and for human intrusion scenarios was modeled. In 1992, closure effects in the disposal room were added by assigning a range of waste porosity, based on a family of waste-void-fraction versus time curves, and fracturing of interbeds was included. Sensitivity analyses on the repository-and-shaft system identify important parameters and modeling assumptions and evaluate the contribution of possible engineered modifications of waste forms. Models for gas generation and radionuclide concentrations will be verified and validated to the extent possible. Alternative conceptual models will be identified and included as necessary. Information needed for this work is discussed in Sections 3.2.1, 3.2.2, and 3.2.3.

The performance-assessment modeling system for consequence analyses includes mesh generators, Monte Carlo sampling, hydrologic flow on different scales, the repository system, and hydrologic transport. The executive package, CAMCON, manages the lengthy and iterative consequence analyses, and minimizes analyst intervention during data transfer. CAMCON manuals are prepared as needed (Rechard, 1991; Rechard, et al., 1989).

Expert Judgment

Technical judgments will be made for the performance assessment. Over the course of the test phase, the use of technical judgments will be evaluated and formalized so that such judgments are consistently used and documented.

Expert judgment is the only means of assigning probabilities to human intrusion scenarios. Expert panels have provided judgments about the societies of the future and principles to guide design of passive institutional controls. Such controls are required by 40 CFR 191.14(c). The effectiveness of these controls, expressed as a probability of intrusion, is necessary for developing the CCDF;

probabilities of intrusion over time are based on the judgments of the expert panels (see Section 3.2.4.2).

A formalized process has been established for eliciting judgments from expert panels, and the WIPP performance-assessment program uses expert-judgment panels. Individuals with diverse educations and experience are selected for particular multidisciplinary panels. The panel members are provided with background information and given a specific statement of work. After a work period, the panel members participate in an elicitation session (to bring out quantitative judgments) and prepare a report documenting their efforts. Expert panels provided probability distributions for the 1992 calculations on the probability of future human intrusion at the WIPP and on the effectiveness of markers in deterring human intrusion (Trauth, et al., 1991; Hora, et al., 1991). For the 1991 calculations (SNL, 1991), expert panels provided cumulative probability distributions of concentrations for the various radionuclides in the repository environment and the retardation of radionuclides in the Culebra. Expert panels will not be used as a substitute for experimental data when appropriate experiments can be performed practically.

3.1.1.3 Uncertainty Analysis

Uncertainty analysis refers to methods for examining variation (uncertainty) in performance predictions that results from variation (uncertainty) in scenarios; conceptual, mathematical, and computational models; simplifying assumptions; or parameters. Uncertainty analysis includes the identification and quantification of uncertainty and its propagation at every significant step of the assessment.

Uncertainties in assessing the performance of natural and engineered systems are evaluated with a Monte Carlo technique using Latin hypercube sampling of the distribution for each input parameter. The Monte Carlo analysis is based on performing multiple model evaluations with probabilistically selected model input and then using the results of these evaluations to determine the uncertainty in model predictions and the importance of the variables that give rise to this uncertainty. Parameter distributions are typically represented as cumulative density functions or the associated probability density functions. Appropriate ranges and distributions for model parameters are chosen for each significant scenario to establish a set of variables for evaluating data uncertainties over all chosen scenarios. Hence, uncertainty analyses for the complex data base and modeling system are inherently probabilistic.

The uncertainty associated with conceptual models is significant and can be the most difficult to identify and quantify. It arises from uncertainties inherent in the model simplifications, because conceptual models are based on the interpretation of available information. Uncertainty in a given conceptual model results from incompleteness of the descriptions, incorrectness and inappropriateness of the descriptions for the purpose, and relationships between descriptions. Several alternative conceptual models may be plausible for a single disposal system.

When a conceptual model is represented mathematically to provide a quantitative description of the system, uncertainty results from necessary approximations. Uncertainty in the conceptual model can be manifested as alternative mathematical equations, each presenting an alternative mathematical model. The complex mathematical models needed in performance assessment often must be solved through numerical approximations by computers, introducing the additional uncertainties of the computational model.

The computational models require parameter values that can be derived from measured data, which are the basis of the conceptual model. Data uncertainty can result from measurements with limited

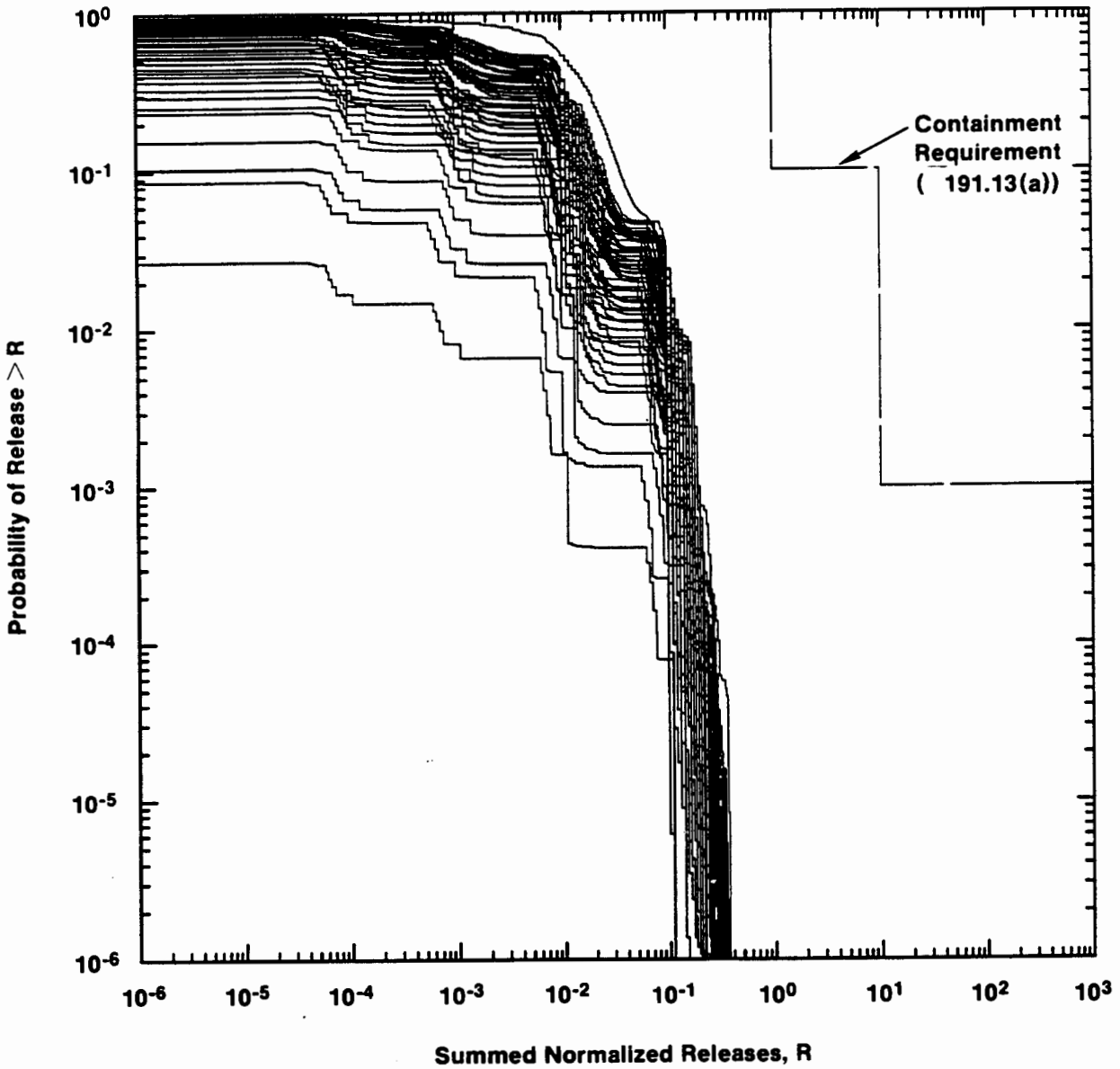


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Figure 3-3. Preliminary Family of CCDFs Showing Total Cumulative Normalized Releases to Accessible Environment Resulting From Both Ground-Water Transport in the Subsurface and Releases at the Surface During Drilling (SNL, 1991).

accuracy and precision, or human error. Uncertainty in parameters may also result from data interpretation and reduction. The size of geologic disposal systems frequently necessitates inferring large-scale behavior from small-scale information; scaling uncertainty affects models and parameters. Uncertainty also results from heterogeneity in natural systems.

Methods and procedures for evaluating and documenting the significance of the sources of uncertainty have been established. These include sensitivity and uncertainty analyses, model verification and validation programs, estimates of experimental error, expert judgment, and peer review.

Those aspects of the performance assessment that contribute significantly to the overall uncertainty in the performance measure should be scrutinized through sensitivity analysis to decide whether the uncertainty can be reduced by collecting additional data.

3.1.1.4 Performance Measure for the Containment Requirements

The performance measures for the long-term performance of the WIPP are the calculated complementary cumulative distribution function (CCDF), the calculated doses, and the calculated concentrations. To date, no release of radionuclides from the disposal system has been predicted under undisturbed conditions (SNL, 1992), and therefore the only performance measure currently being calculated in the preliminary consequence and uncertainty analyses is the CCDF for the containment requirements (40 CFR 191.13(a)). Release means movement of radionuclides into the accessible environment.

If all portions of the CCDF fall within the envelope of the EPA's containment requirements, EPA's guidance states that compliance is indicated; however, complete assurance is not required (see Section 2.1.1.2). Such a result can be seen in Figure 3-3, which shows a family of CCDFs produced from the 1991 preliminary assessment (SNL, 1991). Similar CCDFs will be prepared for the final WIPP performance assessment. Performance assessments produce a distribution (family) of CCDFs for each uncertainty analysis.

In 40 CFR 191.13(a), the EPA requires that the results of the assessment "be incorporated into an overall probability distribution of cumulative releases to the extent practicable." The EPA says that the effects of uncertainties can be incorporated into a single CCDF, and, furthermore, if the single CCDF falls within the probabilistic release limits in 40 CFR 191.13(a), the disposal system will be seen as complying with the requirement. However, all the information provided in the performance assessment cannot be displayed in a single CCDF without losing information on uncertainty. Mean, median, or other summary CCDFs can be produced, and one can be selected as a performance measure. Consideration of only the selected CCDF in evaluating compliance would not be practicable, because important information represented by the family of CCDFs would be obscured. The mean CCDF provides a useful representation of performance, if its relationship to the family of CCDFs is understood. It should be accompanied by the complete family of CCDFs and the associated uncertainty and sensitivity analyses. Any individual CCDFs in the family that exceeds the regulatory limits will be examined. CCDFs that reflect extreme parameter values cause the mean to be skewed toward the least favorable CCDFs in the family, which may add undue conservatism (see EPA, 1985a for discussion on conservatism) to the mean. Judgment is therefore necessary in evaluating the CCDF.

3.1.1.5 Performance Measure for the Individual Protection Requirements

The individual-protection requirements (proposed 40 CFR 191.15(a)) require predicting annual committed effective doses from exposures to radionuclides released from undisturbed performance of

the disposal system during the first 10,000 years after disposal. Preliminary assessments to date, simulating undisturbed performance with the best available models and most complete data sets, indicate that no radionuclides escape from the repository during the first 10,000 years after disposal (Marietta, et al., 1989; Bertram-Howery, et al., 1990; SNL, 1991; SNL, 1992). This implies that dose calculations might not be needed for regulatory compliance. This preliminary conclusion will be re-evaluated as fracturing and other phenomena are included in subsequent performance assessments.

If needed, exposure-pathways modeling would use pathways that begin at the point outside the controlled area where radionuclide-bearing material might be deposited on the surface or withdrawn from the ground water and end with the exposure of people to radionuclides. Doses would be calculated for a typical individual of the critical group at the time each year when the radionuclide arrival peaks.

3.1.1.6 Performance Measure for the Ground-Water Protection Requirements

The ground-water protection regulations (proposed Subpart C at 191.24(a)) require predicting radionuclide concentrations in underground sources of drinking water in the accessible environment. Only releases of radionuclides from the undisturbed disposal system during the first 10,000 years after disposal are considered. As discussed in Section 3.1.1.5, no radionuclides are predicted to escape from the repository during the first 10,000 years.

If releases to the accessible environment are predicted, radionuclide transport by ground water will be modeled to estimate the extent of radionuclide contamination after 10,000 years. Potential underground sources of drinking water in the vicinity of the controlled area will be identified. If the contamination is predicted to reach any underground sources of drinking water (as defined by the EPA in the final disposal regulations) within the 10,000-years travel time, then radionuclide concentrations in that water will be calculated.

3.1.1.7 Sensitivity Analysis

Sensitivity analyses are performed to establish the effect of uncertainty in particular aspects of the model on the uncertainty in model predictions. These analyses show where reductions in uncertainty have the greatest potential to increase confidence in the predicted performance. Because sensitivity analyses are inherently conditional on the scenarios, models, data distributions, and techniques used to generate them, they cannot provide insight about parameters not sampled, conceptual and computational models not used in the analysis in question, and scenarios or processes that have been oversimplified. Judgment about the modeling system and scenarios will be used in combination with sensitivity analyses to determine when the modeling system is adequate.

Sensitivity analyses will be used to determine the importance of the parameters and guide the program while the final conceptual models are being developed. When the final models are established, sensitivity analyses will highlight and examine important parameters and their influence on the uncertainty in total system performance.

3.1.1.8 Interfaces with Research, Development, and Design Activities

The research, development, and design activities of the WIPP Project are designed to provide information for the performance-assessment process, and the results of performance-assessment calculations can provide feedback to guide the activities. This feedback includes uncertainty and sensitivity analyses and peer review. These tasks identify the most important sources (parameters, models, etc.) of uncertainty. The research, development, and design activities develop process

models and gather data to reduce these uncertainties. An interactive, continual interface is necessary for several reasons. The data that are collected must be assembled into a format that is consistent with the modeling approach for the final disposal regulations. The investigations (and the data being collected) will include those that are the most important to predictions of performance and to completing a full and adequate performance assessment. The level of confidence associated with the performance-assessment results will be evaluated. The radionuclide and material inventory for remotely handled and for contact-handled waste will reflect the state of knowledge as it develops.

The development of the performance-assessment data base will involve obtaining data and information from disposal-system characterization and external sources, assembling the data into required formats, and synthesizing them into cumulative distribution functions (CDFs) for model-specific parameters that are used in performance-assessment modeling. Because the disposal regulations require uncertainty analyses, Monte Carlo simulations are performed in which the CDFs for uncertain parameters are sampled over their range of possible values. These Monte Carlo simulations require a complete data base for all performance-assessment models. CDFs are required for all uncertain parameters sampled, and their construction is based on data, judgment by Project scientists, and judgment by expert panels. These functions are preliminary for most parameters and will be adjusted for future performance assessments as sufficient and appropriate data become available. This task will generate a model-specific data base that includes CDFs for all uncertain parameters that will be sampled in the performance assessment for each biennial cycle.

For each performance assessment, the inventory task will update the actinide source term for remotely handled and contact-handled waste, using information from the generator sites for each biennial performance assessment. An inventory of organic and metal constituents that may affect gas generation by corrosion, biological processes, and radiolysis will be developed for the remotely handled waste packages; the existing inventory for the contact-handled waste packages will be updated. Performance-assessment compliance calculations and sensitivity studies require a radionuclide source term and an inventory of the constituents of waste packages that may affect gas generation and radionuclide transport.

As a part of the interface process, uncertainty and sensitivity analyses for performance assessment are performed on the entire modeling system and the individual component models. Sensitivity analyses provide feedback to data acquisition and modeling and design efforts by identifying the parameters with uncertainties that exert the greatest effect on performance. Uncertainty analyses provide the basis for interpreting the level of confidence associated with the performance assessment and will be required for evaluating compliance with the disposal regulations. Interpretation of sensitivity and uncertainty analyses is part of the iterative process of refining the modeling system. This task will assist in setting priorities for additional information gathering and model development, will assist in evaluating engineered-barrier designs, and will provide preliminary information about the level of confidence associated with calculated performance for each biennial cycle. Sensitivity and uncertainty analyses will be performed for the calculations presented in each performance assessment. The uncertainty and sensitivity analyses provide information to the DOE for evaluation of and guidance to the test program.

3.1.2 Assurance Requirements

Because of the inherent uncertainties associated with predicting the long-term performance of the disposal system, the EPA developed assurance requirements (40 CFR 191.14) as a complement to the containment requirements. The EPA designed these assurance requirements to provide adequate confidence that the containment requirements will be met.

Performance assessment is not independent of the assurance requirements; the link between them is illustrated in Figure 2-1. Four of the six requirements influence the outcome of the quantitative analyses:

- Active institutional controls determine the time after decommissioning when human intrusion can first affect the disposal system—at the end of the active control period or 100 years, whichever occurs first.
- Passive institutional controls deter inadvertent human intrusion to an extent to be determined by the DOE, although these controls cannot eliminate the possibility.
- Barriers, both natural and engineered, determine the extent to which radionuclides (and hazardous constituents) escape the repository and are transported toward the accessible environment under undisturbed conditions. Natural barriers determine the extent under disturbed conditions.
- Resources extant in the vicinity of the repository influence the probability of human intrusion.

Inadvertent human intrusion dominates the events that might disturb the repository enough to affect its performance, and efforts to characterize why and how often future societies might inadvertently intrude are nearing completion (Section 3.2.4.2). Guiding principles for deterring intrusion are being established and will be incorporated into plans for complying with the assurance requirements for maintaining active institutional controls (e.g., control over access to the site) and passive institutional controls (e.g., permanent markers and records warning people about the repository). Plans for satisfying the assurance requirements for institutional control contribute to determining probabilities for human intrusion scenarios.

One assurance requirement is influenced by the outcome of the performance assessment: guidance for monitoring the disposal system after decommissioning may be developed from the results of the undisturbed-performance predictions.

Only one assurance requirement is not related to the performance assessment: removal of the wastes for a reasonable time after disposal is not precluded. The EPA acknowledged in promulgating 40 CFR 191 that "any current concept for a mined geologic repository meets this requirement without any additional procedures or design features (EPA, 1985c)."

As more is learned about the uncertainties associated with radionuclide containment within the disposal system, the plans for meeting the assurance requirements will be refined to complement the capabilities of the disposal system. Plans for implementing the assurance requirements have been developed (DOE, 1991c).

3.2 INFORMATION NEEDED FOR COMPLIANCE

This section describes the activities designed to satisfy the information needs identified in the compliance program structure (see Figure 2-1). Most of the activities conducted during the test phase will provide information for the performance assessment for 40 CFR 191, Subparts B and C. They are discussed below relative to the information needs in the following order: Natural Barriers (Section 3.2.1), Repository Design and Engineered Barriers (Section 3.2.2), Waste Interactions (Section 3.2.3), and Human Intrusion (Section 3.2.4). More-detailed information about the studies that make up these activities is given in Chapter 5.

Regardless of the type of information gathered, some processing is usually necessary before the information can be useful for performance assessment. The processed data may be combined with other information and then put into a form useful for performance assessment, such as the form of parameter sets with distribution functions or models with associated assumptions and in a form suitable for multiple Monte Carlo analyses. The latter require a great deal of computer time, and therefore some information must be converted to an equivalent but more computationally efficient form. This process requires a high level of technical judgment, time, and documentation.

3.2.1 Natural Barriers

The Salado Formation, which is the host rock for the planned repository, and the rock units above the Salado play an important role in the performance of the WIPP: preventing or inhibiting the migration of radionuclides and gases released from the waste to the accessible environment. To date, the scenarios that have been developed to predict long-term performance have indicated that one unit—a dolomite layer known as the Culebra Dolomite Member of the Rustler Formation—could provide a pathway to the accessible environment, especially in the event of inadvertent human intrusion (e.g., exploratory drilling for petroleum resources) into the repository (see Figure 1-3).

Three sets of activities are designed to provide information about the natural barriers of the WIPP disposal system. The two activities that will provide the information and understanding needed to evaluate the ability of the Culebra and surrounding units to adequately contain the waste stored in WIPP after inadvertent human intrusion are the Non-Salado Hydrologic Properties (Section 3.2.1.1) and the Non-Salado Transport (Section 3.2.1.2) activities. The second set of activities comprises investigation of the hydrologic and transport properties of the Salado Formation. These two activities are Salado Hydrologic Properties (Section 3.2.1.3) and Salado Transport (Section 3.2.1.4). The third set comprises studies that have yielded all the information about the site that has been collected prior to the test phase, or, Site Characteristics (Section 3.2.1.5). Any subsequent activities to publish or further interpret data collected during the Site Characterization phase will be included in the first two major activity sets.

3.2.1.1 Non-Salado Hydrologic Properties Activity

Objective

The Culebra Dolomite Member of the Rustler Formation (see Figure 1-3) is the most transmissive rock layer above the planned WIPP repository. Information obtained as part of the Site Characterization indicates that the Culebra is continuous across the disposal system and is saturated with slow-moving saline ground water. The Culebra could provide a pathway for radionuclides to be released to the accessible environment if a future borehole breaches the repository. According to this scenario, radionuclides could be transported up the borehole, into the Culebra, and carried by moving ground water to an off-site stock well. Predicting possible pathways and travel times for radionuclides in the Culebra to reach the accessible environment is one of the critical tasks of the performance assessment. These pathways and travel times strongly depend on the rates and directions of ground-water flow in the Culebra and other rock units above the Salado Formation over the time periods of regulatory concern.

Uncertainties in long-term predictions of ground-water flow continue to exist for the WIPP site. Currently, two-dimensional flow-models (confined aquifer models) are used to evaluate data from pumping tests and calibrate transmissivity distributions. These models make the critical assumptions that ground-water flow is in equilibrium with boundary conditions and that vertical flow between the Culebra dolomite and other units in the Rustler Formation can be neglected. These assumptions are

probably appropriate for the relatively short durations of the pumping tests. However, predictions of long-term paths and travel times for radionuclides derived from the confined aquifer models are considered to be tentative because these assumptions may not be appropriate for periods of thousands of years. The appropriateness of these assumptions is considered to be an important source of uncertainty, referred to as conceptual model uncertainty, in the performance-assessment process. Other reasons current predictions must be considered to be tentative are: (a) data from several pumping tests have not been fully analyzed and reported, (b) the effect of climate change on the confined-aquifer model boundary conditions has not yet been determined, (c) the confined-aquifer model might not be consistent with geologic, geochemical, and isotopic information, (d) current scenarios in which gas enters the Culebra from the breach borehole have not been fully examined for the effect of the gas on Culebra flow, and (e) uncertainty due to spatial heterogeneity in flow properties and related scale-up of test data has not yet been fully assessed.

To improve predictions of ground-water flow over the next 10,000 years, the following questions must be addressed. Is the ground-water system in the WIPP region in steady state or is it draining from an earlier pluvial period? Will rates of ground-water flow change in the future? How would potential climatic changes affect the path and time of radionuclide travel to the accessible environment? What effects do vertical leakage and variations in the density of ground water have, and can they be neglected? Do existing petroleum boreholes that are outside the WIPP controlled-area boundary and that penetrate the low permeability units in the Rustler Formation affect ground-water flow? Are the current conceptual models of the WIPP ground-water flow consistent with all the existing site characterization data, especially the geochemical data? How will gas flowing into the Culebra affect the flow patterns? Does existing data preclude severe spatial heterogeneity in flow properties, or hidden features? What is the uncertainty in flow predictions from severe heterogeneity or hidden features that cannot be precluded on the basis of the data? Are there potential underground sources of drinking water in the vicinity of the disposal system?

Relevance to Compliance

To answer the above questions, it is necessary to consider the hydrologic behavior of the Culebra near the WIPP as part of a regional hydrologic system that includes all of the rocks above the Salado and extends to the natural boundaries of the regional ground-water system. The technical approach is to build a transient three-dimensional model of ground-water flow for the WIPP region. This model will be based on the concept of the ground-water basin. It will be used to examine the potential effects of water-table fluctuations resulting from climatic variations, vertical leakage through low-permeability strata, spatial variations in density, and nearby drilling on flow patterns in the Culebra. The ground-water-basin model will also be used to address conceptual model uncertainty and, if required, provide boundary conditions for confined aquifer models (to allow better calibration of the transmissivity field at the WIPP site and reduce uncertainty in radionuclide release predictions). In a separate effort, the response of the Culebra to a discharge of brine and gas from the repository will be examined (see Section 3.2.4). Unless the presence of gas causes a major perturbation in Culebra flow patterns, the ground-water-basin model will not be modified to include flowing gas. However, the presence of gas in the Culebra could have a significant effect on the transport of radionuclides.

A large amount of data, including information from 60 wells at 41 locations, is available for the Culebra. In contrast, few data are available for other transmissive units above the Salado and essentially no information is available for the units with extremely low permeability. It will be necessary to infer properties of these units by mapping and synthesizing existing geological and geochemical data. Laboratory measurements of flow properties may be made on existing core samples from units other than the Culebra, such as the Dewey Lake Red Beds, to provide additional data. Geochemical models will be used to further refine and interpret data collected during site

characterization. The hydrologic data base will also be (incidentally) enlarged by a field tracer test currently proposed for resolving issues associated with radionuclide transport.

National and international collaborative efforts will be pursued to obtain support for modeling approaches and to obtain insights from similar projects. Experts in relevant specialties may also review the modeling and to provide assessments of the technical strength of conclusions drawn. Technical results will be submitted to journals, where appropriate. Ongoing studies will be reported periodically; test data, models and model inputs will be available for scrutiny by appropriate technical review groups.

Performance-assessment calculations require information in the form of parameter distributions, recommendations for model implementation, and evaluations of alternative conceptual models. The Non-Salado Hydrologic Properties activity is designed to provide this information for performance-assessment calculations of off-site travel paths and travel times in the absence of radionuclide retardation. In addition, data interpretation and model validation studies are designed to provide the performance assessment with a sound technical basis. Until all pumping-test interpretations are completed and reported, parameters currently used in the performance-assessment model will lack supporting documentation.

The hydrologic data and modeling approach currently used for the performance-assessment calculations for the WIPP have been included as part of the Culebra test case submitted to the INTRAVAL (an International Project to Study Validation of Geosphere Transport Models). International teams working on the WIPP Culebra test case, as well as the NAS review panel, have raised important questions about the Project's current understanding of the ground-water flow around the WIPP. Many issues are being resolved by the INTRAVAL participants; many will be resolved by Project activities. Resolution of some issues will be limited by state-of-the-art technical capabilities; prevalent expert judgment must be invoked in these cases.

The development of a ground-water-basin model for the WIPP region will improve predictions of travel times and transport paths of radionuclides in the Culebra dolomite associated with a borehole intrusion. The ground-water-basin model is also the best available tool for testing the validity of alternative conceptual models of ground-water flow. Success of this work depends on such studies as computer code development, synthesis of geologic and geochemical data, and geochemical modeling.

3.2.1.2 Non-Salado Transport Activity

Objective

If radionuclides were transported up a breach borehole and into the Culebra, the transport pathway and travel time would strongly depend on the long-term ground-water flow in the Culebra and in the surrounding formations. The other major controls on radionuclide transport to the accessible environment are the retardation factors for the radionuclides traveling through the Culebra. The retardation factor for a radionuclide is the ratio of the velocity of the ground water to the velocity of that radionuclide dissolved in, or in the case of colloids, transported with the ground water.

The retardation of radionuclides can occur in the brines and rocks of the Culebra by physical retardation, without chemical reactions. The Culebra generally contains both intercrystalline and fracture porosity. The fluid flow through a rock with such a fabric is thought to be best characterized by a "double-porosity" system, in which most of the ground-water flow is through the network of interconnected open fractures. The large volume of dolomite surrounding the interconnected fractures is, on average, 16 percent porous, which may provide significant storage for ground-water

contaminants. Radionuclides dissolved in ground water flowing through the fractures can diffuse into the large volume of surrounding dolomite, significantly retarding the transport of the radionuclides to the accessible environment. The degree of physical retardation can be enhanced by chemical reactions within the dolomite.

Chemical processes that lead to radionuclide retardation can occur in the absence of physical retardation, but are enhanced by physical retardation. Chemical processes that lead to radionuclide retardation include adsorption onto rocks in the Culebra, ion exchange with Culebra constituents, and precipitation from ground water to a non-mobile solid. On the other hand, colloids containing radionuclides, if shown to occur, could inhibit both physical and chemical retardation.

Given the importance of retardation in the Culebra to the performance of the WIPP disposal system, the following questions must be resolved before radionuclide retardation can be proved. Is the Culebra a double-porosity system over the entire pathway or significant portions of it? If double-porosity cannot be demonstrated incontrovertibly, what other transport models must be included in the performance assessment? What are the long-term transport implications of those models? If double porosity cannot be demonstrated incontrovertibly, how strong can the case be made to support the assumption of double porosity? What is the physical retardation factor in the Culebra dolomite with and without simultaneous chemical retardation? What chemical retardation processes will operate in the Culebra for each radionuclide that can reach the Culebra, with and without simultaneous physical retardation, for each water composition and rock type encountered along the probable flow path? Can colloids exist in the brines of the Culebra? If so, how will colloid formation and transport affect retardation? What will be the effect on radionuclide retardation in the Culebra dolomite of waste-generated gas entering the Culebra from the repository via the breach borehole?

Relevance to Compliance

Physical retardation can, for the most part, be modeled independently of chemical retardation. However, only for the most simplistic chemical retardation models can chemical retardation be modeled independently of physical retardation. Validated models for each retardation mechanism will be used to predict the effect of both mechanisms operating simultaneously. The various chemical retardation mechanisms are not as easily separated, requiring a carefully planned series of single-effect and integrated-effect chemistry experiments and model development to yield defensible radionuclide retardation data for the Culebra.

In the case of physical retardation, the validation of the double-porosity model for the Culebra uses data from field and laboratory experiments. Laboratory experiments will demonstrate the presence and rates of matrix diffusion into samples of Culebra rock taken from a few locations along the predicted travel path. Data from field tracer tests will be used to demonstrate matrix diffusion over the 6- to 60-meter scale of the tracer test. Scaling calculations and large-scale pumping test data will be used to extrapolate the 6- to 60-meter scale information from the tracer tests to the kilometer-scale transport pathway.

Participants in the INTRAVAL international program were presented the existing, strong evidence proposed for validation of double porosity transport, namely, an integrated interpretation of all the tracer tests conducted during site characterization. In response, they proposed a channeling model as a possible alternative conceptual model of transport in the Culebra. Such a model would have significantly different implications for long-term transport than the double-porosity model. As a result, an additional field tracer test will be conducted which will be designed to differentiate between a double-porosity transport model and a channeling transport model. International participation will be encouraged in the design and interpretation of the test.

To provide more data on chemical retardation, single-effect experiments are investigating solubility, adsorption (thought to be the dominant mechanism for the retardation of radionuclides in the Culebra), colloid formation, and precipitation/coprecipitation. For each mechanism of interest, either the experiments should supply sufficient information for the use and validation of mechanistic predictive models, or they should supply information for all radionuclides of interest and for all combinations of minerals, brines, and man-introduced material (e.g., leached organics) present in the Culebra; that is, they should span the entire parameter set of interest. The approach chosen to supply predictions for each mechanism (adsorption, precipitation, ...) will be the most efficient means to obtain the required predictions for that mechanism.

Integrated-effects tests (column experiments, including a long-core experiment, and a proposed field sorbing-tracer test) will be used to determine the total retardation due to combined chemical and physical retardation processes. The column experiments should distinguish among the retardation effects of colloids, matrix diffusion, and chemical retardation. Batch tests, though they test integrated effects, address only sorption, from which retardation must be extrapolated. Only a limited number of column experiments and a single, field, sorbing-tracer test will be performed; therefore, transport-model development is essential reliably predicting chemical retardation and how it varies along the entire release pathway. The column experiments and field tracer test are designed to provide calibration or validation or both of a transport model that will be developed using information gleaned from single-effect experiments. Calculations will be performed to predict how much waste-generated gas could be released to the Culebra and its effect on retardation processes. Laboratory measurements may also be performed to determine the effects of gas, if scoping calculations indicate that the experiments could yield important data.

Data from laboratory and field experiments will be compiled into a data base and will provide retardation probability distributions to the performance assessment for incorporation in performance-assessment calculations. The Non-Salado Transport activity is designed to provide additional support to the performance assessment in the form of double-porosity-model validation.

The 1990 and 1991 preliminary assessments for the WIPP disposal system clearly show the importance of retardation processes to compliance with the disposal regulations, and the State of New Mexico has specified in the Consultation and Cooperation Agreement that the DOE is to demonstrate experimentally the actual range of retardation factors to be expected in the Culebra, unless no retardation is assumed. Data for predicting defensible values for effective retardation factors in the Culebra are not available. However, the program outlined above—combining modeling, separate-effect experiments, integrated-effect experiments and field tests—is designed to provide the legal and technical basis for using radionuclide retardation in demonstrating regulatory compliance. It will allow retardation in the Culebra to be addressed in a clear and rigorous scientific framework and in a timely manner.

3.2.1.3 Salado Hydrologic Properties Activity

Objective

The hydrologic properties of the host rock for the WIPP—the Salado Formation—must be adequately understood for both the human intrusion scenarios and the undisturbed scenario. In the case of human intrusion, the hydrologic characteristics of the Salado are important influences on the disposal-room environment over the long term. In the undisturbed case, Salado hydrologic characteristics in combination with the shaft seals determine the degree to which the planned repository can isolate the waste from the accessible environment. Key issues for both the undisturbed and disturbed cases are these questions: Can the formation provide significant quantities of brine to the waste rooms? Can

the formation serve as a sink for significant quantities of waste-generated gas? In the absence of an intrusion into the repository, will the Salado Formation provide a barrier to the transport of fluids and radionuclides from the repository to the accessible environment for the next 10,000 years?

The Salado consists of stratified layers of relatively pure salt (halite), layers of argillaceous halite with varying clay content, clay seams, and anhydrite layers. The anhydrite layers appear to have higher permeability than the halite layers. Two important anhydrite layers, MB 138 and MB 139, lie within a few meters of the repository horizon. The stratification in the Salado is well defined and persists for long distances, on the order of kilometers. The nature of fluid flow in the halite and anhydrite layers is incompletely understood. Because pure halite is a "plastic" material, it has been widely believed that the entire formation is impermeable under lithostatic pressure. Some data contradict this belief. Results from several Salado testing programs have allowed the refocusing of testing efforts, ultimately aimed at the key questions stated above, to a series of more specific questions; namely, What is the permeability, porosity and pore pressure in the anhydrite layers in the far field? To what extent do the anhydrite layers control flow in the Salado? Do the halite layers behave as a low-permeability continuum over large distances? Or is halite actually impermeable in its undisturbed state, with flow occurring only in regions near excavations with high deviatoric stresses? How is flow in the anhydrite layers influenced by the surrounding halite layers? Are there significant flow heterogeneities in the Salado and, if so, do sufficient interconnected pathways exist within the formation that an effective non-zero far field (or bulk) permeability can be defined? Will pre-existing fractures in the anhydrite layers open when pressurized by waste-generated gas and allow easy gas dissipation into the far field?

Relevance to Compliance

Data characterizing Salado gas and brine flow are collected in laboratory and field-scale experiments. Laboratory testing is focused on obtaining marker bed data to characterize both gas and brine flow, including measurements of two-phase characteristics, gas threshold pressure, intrinsic (single-phase) permeability, porosity, and capillary fingering. Of particular importance are data and models for gas dissipation. Field testing is or will be at a variety of test scales and includes localized permeability testing of specific stratigraphic units (intrinsic permeability, pore pressure, and threshold pressure), small- and intermediate-scale brine-inflow experiments spanning several stratigraphic units and a large-scale brine-inflow experiment. The large-scale brine-inflow experiment includes measurement of cumulative brine inflow, pore pressure and permeability changes at various locations in the surrounding rock, geomechanical measurements of room closure, and geophysical measurements characterizing near-field changes in rock saturation. An issue for all laboratory and field tests is the distinction of disturbed rock zone effects from the hydrologic properties of the undisturbed rock. A series of hydrofracture tests is being conducted in anhydrite layers to determine the pressure at which fractures open or propagate or both, the nature of fracture propagation, and the hydraulic characteristics of the induced fractures. Geologic, geochemical (brine chemistry and gas solubility) and geophysical information is sought when not already available, and it yields insights into the hydrologic properties of the Salado that may be unavailable by direct measurement. Data bases are managed to assure that data records meet quality standards, are published, and are widely available for scientific review. The experimental and data-base studies are designed to provide the data necessary to develop and test various conceptual models describing flow in the Salado Formation.

Modeling includes development of conceptual models, particularly alternative conceptual models describing flow in the Salado; development of detailed numerical models based on conceptual models; use of numerical models for sensitivity studies, test design and test interpretation; and conversion of detailed models to efficient performance-assessment models; or benchmarking of detailed models against performance-assessment models, or both. Test interpretation with alternative

models, data error analyses, and uncertainty analyses will be used to generate uncertainty distributions for flow parameters used in the compliance assessment. Validation of conceptual models of flow in the Salado will be pursued through participation in the INTRAVAL and similar work and will provide validation of performance-assessment models.

The models and data describing flow in the Salado are essential components of the disposal-room model (Section 3.2.2.1), which is necessary for the performance assessment for the disposal regulations and for RCRA. These models will allow all the important physical processes controlling development of the disposal room environment to be interactively modeled.

3.2.1.4 Salado Transport Activity

Objective

Related to issues of brine and gas flow in the Salado surrounding the waste rooms is the issue of transport of radionuclides or hazardous materials into and through the Salado. It is likely that the preferred travel path through the undisturbed Salado will be through the anhydrite layers, specifically MB 138 and MB 139 and anhydrite beds A and B. Transport in the liquid phase is the predominant focus of research for migration of radionuclides and hazardous materials. However, if a significant amount of gas is generated by the waste, gas-phase transport will be important for VOCs. Thus, major questions are centered around the nature of transport in the marker beds. What is the importance of capillary fingering or channeling to the flow of waste generated gas from the repository? Is flow primarily fracture flow? Is double porosity present? What retardation mechanisms are expected to operate in the marker beds?

Relevance to Compliance

The technical approach for addressing this issue is to conduct laboratory- and field-scale experiments to characterize transport in the anhydrite layers within the Salado. Laboratory testing will obtain marker bed data (gas and fluid transport), focusing on demonstration and characterization of capillary finger formation, fracture flow and matrix diffusion in the anhydrite layers. A field transport test is currently planned for MB 139. Fundamental brine and rock chemistry information will be obtained if existing site characterization data are insufficient to identify the operative retardation mechanisms. These experiments are designed to provide the data necessary to develop transport models for use in performance assessment and other system-scale sensitivity studies.

The answers to the questions about the extent to which the transport of radioactive and hazardous materials can occur in the undisturbed scenario require information in addition to that discussed under "Salado Hydrologic Properties Activity." Together they are designed to provide the information needed to develop a flow and transport model of the Salado Formation. This overall flow and transport information is necessary for repository modeling that accounts for interactions between the repository and the surrounding Salado salt.

3.2.1.5 Site Characteristics Activity

Objective

Extensive geologic, hydrologic, geochemical, geophysical and isotopic investigations have taken place in the vicinity of the WIPP site, beginning in 1975, primarily to resolve issues concerning the hydrology of the Culebra Dolomite Member of the Rustler Formation. The Culebra dolomite, the

most transmissive saturated stratum above the repository, creates a potential pathway for radionuclides to travel laterally from a location immediately above the repository to the disposal-system boundary.

These studies included detailed investigation of numerous surface features to delineate subsurface features or irregularities that could affect flow in and around the Culebra dolomite. The wells in the Culebra dolomite provided information on the hydrologic properties of the Culebra. Culebra geochemistry and isotope studies have been conducted to obtain additional insight into the hydrologic behavior of the Culebra. In general these data have been used to demonstrate that the age of the Culebra waters near the disposal system is of the order of 10,000 years, and that the waters originated during a known pluvial period. A transient electromagnetic survey was recently completed to better delineate a hypothesized fractured region (high transmissivity zone) in the southeast corner of the site.

In spite of extensive investigation, several questions remain about the WIPP site characteristics: How narrow is the high transmissivity zone southeast of the repository, and exactly where is it? Does local recharge occur?

Relevance to Compliance

Extensive surface-based data gathering was completed during the site characterization phase. Additional testing, modeling or documentation may be undertaken to address specific issues or outstanding questions known to be of importance to the performance assessment (e.g., the proposed large-scale tracer test in the Culebra). New geotechnical capabilities that will permit resolution of important outstanding issues in both testing and modeling may be used in the future as they become available. For example, analysis of recent electromagnetic survey data from regions near the high transmissivity zone will continue. The WIPP Project monitors ongoing investigations of proposed techniques to directly measure ground-water recharge rates, conducted at a local university. Long-term monitoring of water levels in Culebra wells is ongoing to detect unexpected changes in ground-water behavior. Reports may be written that assemble data and arguments used by the Project, during site characterization, to disprove the existence of extreme geologic features (e.g., karst fractures) surrounding the WIPP.

The existing site characterization data form a significant data base. Gathering of additional geologic/geochemical information will take place, if it will allow resolution of outstanding issues for the Project or add important new data to the existing data base. Although the surface-based data-gathering work has largely been completed, some data are still to be analyzed to resolve potential inconsistencies between geochemical and hydrological conceptual models. Subsurface karst features continue to be postulated by intervenors, although the DOE concluded during site characterization that existing data do not support the hypothesis.

3.2.2 Repository Design and Engineered Barriers

Both the repository design and the engineered barriers affect the performance of the repository system. The repository design is completed and a significant portion of the facility has been constructed; hence, design features related to performance are relatively well established. These include the layout of the planned repository and the operations that could impact performance (number of panels, number and sizes of rooms in each panel, amount and distribution of waste emplaced in each room, footprint of the repository, distance to marker beds, etc.). Performance evaluations of engineered barriers will predict the behavior of the disposal room and efficacy of the seals placed in shafts, drifts, panel entries, and boreholes.

The principal products of the seal activities are feasible designs that meet the performance requirements and performance models for the seals, including the associated data base. Numerous interactive studies are necessary to produce the designs and models (Figure 3-4).

Disposal room performance evaluations (Section 3.2.2.1) will simulate the coupled mechanical, hydrological, and chemical processes associated with the waste and the surrounding host rock. Performance evaluations of the seal systems (Section 3.2.2.2) consider the disposal phase and the period after decommissioning to determine whether these systems perform the short- and long-term functions required of them. For purposes of seal system discussions in this Section (3.2.2), the phrase "long-term" identifies the time period that begins when the emplaced salt components become effective seals (approximately 100 years after seal emplacement) and continues throughout the disposal regulatory period. "Short-term component" identifies those components required to be effective prior to reliance upon the long-term components. These evaluations depend upon understanding and predicting the behavior of the seal materials (crushed salt, concrete, clay, grout, and other materials) in the WIPP environment. The performance evaluations will be based on detailed designs of the seal systems (Section 3.2.2.3). Only through such designs (and associated demonstrations) can emplacement feasibility be established. Those demonstrations will also increase confidence in assumptions made in performance-assessment calculations related to the initial performance and behavior of the seals.

Two important supporting technology activities related directly to the performance of the engineered barriers are evaluations of the permeability of the disturbed rock zone (Section 3.2.2.4) around the excavation and evaluation of the closure of shafts, drifts, and boreholes (Section 3.2.2.5). Both of these activities provide analytical models of the behavior of the host rock that are critical parts of assessing fluid flow past seal components or fluid flow related to the performance of the disposal room.

3.2.2.1 Disposal-Room Performance Activity

Objective

Strongly coupled mechanical, hydrologic, and chemical processes are likely to have a profound impact on the waste-room environment. Closure of the disposal rooms begins immediately after excavation, as the salt surrounding them begins to creep closed. Simultaneously, intercrystalline brine begins to migrate toward the disposal room. After waste emplacement, gas generation is expected initially to be due largely to radiolysis and microbial activity. Once brine enters the room and contacts the wastes, however, gas generation rates of all three major gas generation mechanisms (corrosion, microbial gas generation, and radiolysis) will be increased by contact with water, and microbial activity may increase as well. The currently accepted understanding of room consolidation suggests that the room will continue to close because of salt creep until the total gas pressure and mechanical backpressure from the waste and backfill stop consolidation and brine inflow. The room pressure can then slowly approach the pressure of the lithostatic overburden, in an equilibrium condition. However, continued gas generation after equilibrium would require either that the room expand; that excess gas migrate away from the room along existing gas-migration paths; or that fracturing occurs in the halites, interbeds, or anhydrite marker beds within the host rock of the Salado Formation surrounding the disposal rooms, thus creating migration paths for gas (and brine) to move away from the disposal room.

The objective of constructing the disposal-room model and conducting the calculations is to provide information for performance assessment describing the disposal-room porosity and permeability of the waste and backfill as functions of time, as well as examining the sensitivity of Salado fluid flow to the

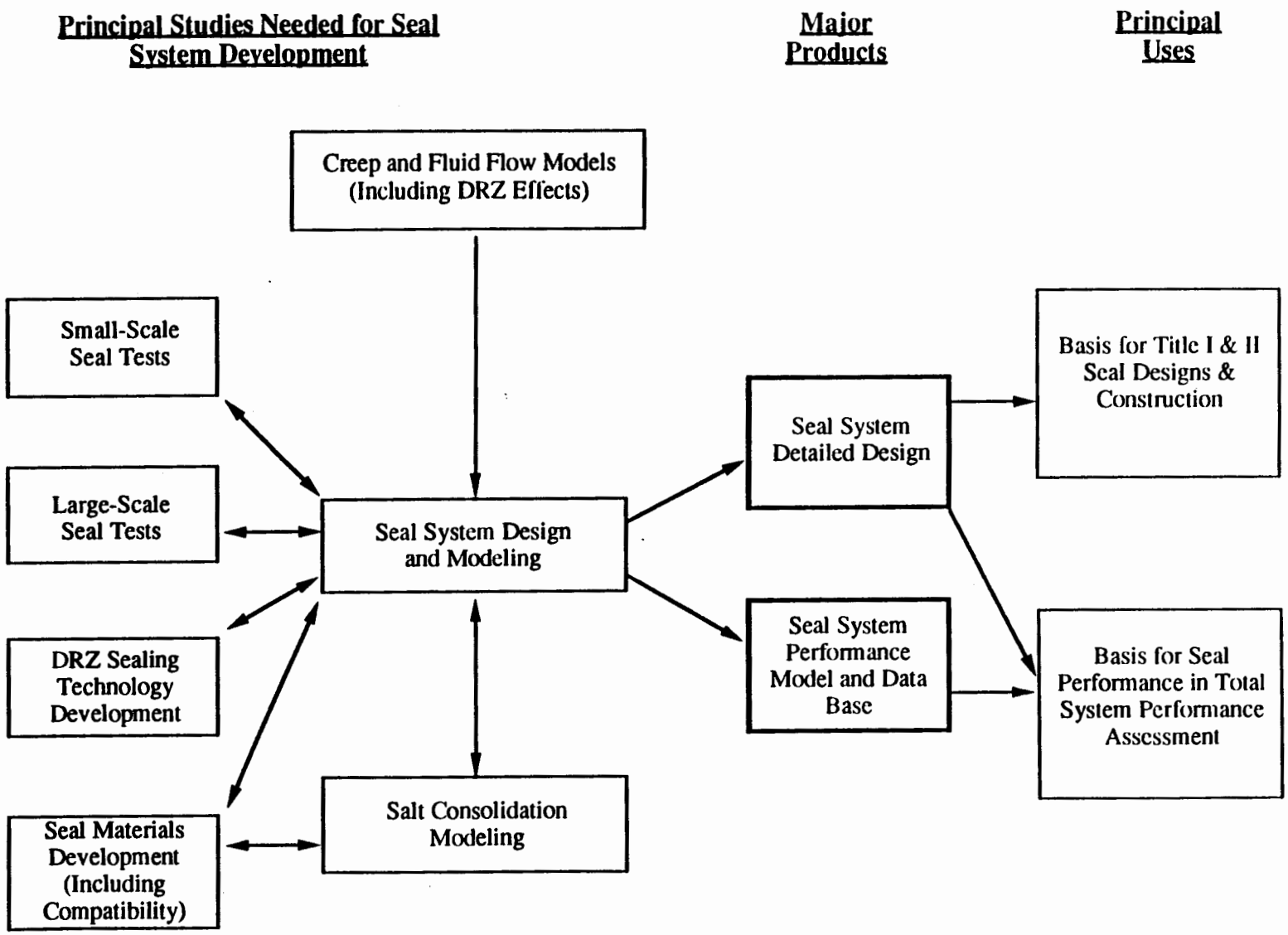

Figure 3-4. Principal Seal Program Studies, Products, and Their Uses.

gas generation and disposal room conditions. Information concerning fracture formation and propagation as a function of pressure, as well as any pronounced stress effects on hydrologic properties are also of interest. The transfer of information from the disposal-room model may be accomplished by incorporating various portions of the model directly into performance-assessment models, if the disposal-room model is computationally efficient. This direct transfer is unlikely, however, because the strong coupling among the various processes involved in room response make the overall model inefficient for iterative analyses. Instead, redefinition of the room model and related information for purposes of performance assessment, in the form of more efficient models, such as a three-phase model or data tables, is likely to be necessary.

The current research for this activity is intended to provide answers to the following questions. What are the physical couplings among room creep (including salt and anhydrites), gas generation, gas migration/dissipation, and brine inflow/outflow? To what extent will gases dissipate into the Salado Formation and marker beds with and without enhanced permeability in response to gas generation? To what extent does brine availability impact gas generation rates and effective gas generation potentials? To what extent does room closure impact room pressurization and associated flow into and out of the disposal room? Will the disposal-room gas pressures become sufficiently high to propagate existing fractures in the marker beds or initiate new fractures? How would the expected disposal-room response be altered if waste or backfill or both were altered?

Relevance to Compliance

The technical approach to understanding the migration and dissipation of gases in the Salado and the effect of gas getters in the backfill materials is to develop a rigorous set of models describing gas generation within the disposal room, two-phase fluid flow (gas and brine) in the Salado, creep closure and consolidation of the disposal room and backfill, fracturing behavior of the interbeds within the Salado, and the physical coupling among the several processes and model elements. A series of laboratory experiments will establish the necessary parameter set for each component of the overall model, such as creep properties of the salt; two-phase-flow properties of the salt, anhydrite marker beds, backfill, and waste; and gas generation as a function of the waste materials placed in the disposal room. The Project baseline is disposal of unmodified or untreated wastes, using a salt or salt-bentonite backfill. Consideration of engineering alternatives to this baseline, such as various types of waste processing, or changes to the backfill constituents, would change the expected consolidation response and fluid-flow properties of the disposal room, and would require additional modeling. As appropriate, information is collected from field studies to evaluate parts of the disposal-room conceptual model.

In-situ tests will measure the behavior of fractures in the anhydrite and salt/anhydrite interfaces of MB 139 and MB 140 (see Figure 1-3). Field and laboratory experiments will measure the threshold pressure (pressure required to drive gas into a brine-saturated rock) and relative brine and gas permeabilities for the Salado. In-situ studies will yield information about both the consolidation of waste and backfill and the role of brine wicking in salt and salt/bentonite backfill materials.

This research will support the development and evaluation of numerical models that couple the physical processes important in the response of the disposal room, such as salt creep, backfill consolidation, waste-form compaction, gas generation, gas migration, and brine inflow and outflow. Then, either these models or the information resulting from use of the models must be incorporated into the modeling system for the performance assessment. The development of a three-phase model is an effort to couple multiphase fluid flow with the room closure/consolidation processes that are simulated in detail by mechanistic creep/closure calculations.

Pressures resulting from the combination of gas generation by waste degradation with room consolidation may alter brine inflow into the disposal room, and may cause gas migration or dissipation without structural changes through the shaft seals, the Salado Formation as a whole, or the anhydrite marker beds. Alternatively, if gas generation is extensive enough, it may lead to fracture initiation and/or dilation in stratigraphic layers near the repository. The range of possible responses to gas generation can profoundly affect the state of the repository under both undisturbed conditions and during a human intrusion event, changing ground-water movement and contaminant (radioactive or hazardous constituents) transport within the disposal room and in the surrounding formation.

Models supply information regarding gas, brine, porosity, and permeability in the disposal room and describe the possible impacts on the flow paths for brine and gas in the repository and through the Salado marker beds. Furthermore, these models describe the physical behavior of the disposal room in greater detail than necessary for the performance assessment. Therefore, they are expected to be more descriptive in predicting disposal-room behavior. The more detailed models identify those phenomena that either must be considered or can safely be ignored in performance assessments. The three-phase model may allow the Project to better understand and represent the relationship of room dynamics and fluid flow for the performance assessment.

3.2.2.2 Shafts, Drifts, and Boreholes Seals Performance Activity

Objective

Seals and plugs are designed to prevent shafts, drifts, panel entryways, and boreholes from becoming preferential pathways for escape of regulated waste constituents. Short-term shaft seals and borehole plugs are also necessary to prevent intrusion of ground water into consolidating crushed salt seal components and disposal rooms from water-bearing zones in the Rustler Formation until long-term seals take over that function. Short-term drift and panel entryway seals are necessary for operational safety during the disposal phase and to assist consolidation of salt sealing components by confining the components.

The objective of this activity is to provide models of the performance of sealing system components and values for the parameters needed for those models for incorporation into the performance assessment. The models and recommended parameters will be based on combinations of laboratory measurements, field measurements, and detailed numerical analyses. Laboratory measurements of the properties of seal materials will establish the anticipated range of values at the time of emplacement and after interactions with the WIPP environment. Field measurements of the initial performance of seal components will demonstrate the behavior of selected components in the WIPP environment. Detailed numerical analyses of component performance will evaluate both the structural integrity and flow resistance of components; these analyses will evaluate the more empirical models used directly in the performance assessments to assure that the range of behaviors predicted by the detailed models is captured by the performance-assessment models. These evaluations (and associated measurements) are intended to confirm the conceptual models used to simulate the behavior of the seals; particular emphasis is upon evaluations of the models of salt-seal consolidation, characterizations of the disturbed rock zone and its subsequent healing, and potential short-term (< 100 years) flow past concrete, clay, and bitumen components of the seals.

Research, development, modeling, and design studies in this activity focus on answering the following questions. How long will it take for seal materials made of salt to consolidate into effective long-term seal components? What is the flow resistance of individual seal components and seals as a function of time for operational and long-term regulatory periods? What is the overall performance of the sealing system for limiting flow as a function of time for the three periods of institutional control? Will the

clay, concrete, and grout short-term seal component materials be sufficiently stable in WIPP host rocks and brines to perform adequately during their required lifetime? What are the permeabilities, porosities, and other materials properties as functions of time? What materials formulations resist geochemical degradation? Are there interactions that will occur between seal materials and hazardous constituents that may decrease seal performance? What evidence is there that the seals can be designed and built to perform as predicted?

Relevance to Compliance

The technical approach to predicting sealing effectiveness as a function of time is to conduct laboratory experiments for development and characterization of seal materials; conduct experiments and in-situ tests to characterize the disturbed rock zone and assess efficacy of small-scale seals; generate seal models based on materials properties and seal designs; and demonstrate emplacement technology, as well as initial performance, that meets design requirements. Laboratory experiments are intended to determine the consolidation properties of crushed-salt seal materials; determine fracture healing kinetics in salt; and develop short-term seal materials that are sufficiently stable geochemically, are compatible with hazardous constituents, and meet other emplacement- and performance-related requirements. Models of materials behavior and seal components are derived from the results of the experiments using design concepts. Models of disturbed-rock-zone healing kinetics will also be developed. Component and materials models are integrated to produce tractable overall performance models. Small- and large-scale in-situ tests will demonstrate emplacement technology and initial performance that meets design criteria.

Concrete and grout materials must be developed and characterized for use in the different brines of the Rustler and Salado Formations. Because permeabilities and other properties are affected by chemical change or degradation, laboratory experiments will be designed to measure kinetics of degradation reactions and identify materials formulations resistant to chemical attack by Rustler and Salado brines and by mobile constituents released from the TRU mixed waste.

Although numerous boreholes have been drilled from the surface of the WIPP site, none penetrate the repository. Most of the nearby boreholes are relatively shallow and have several hundred feet of intact salt vertically or horizontally or both between them and the repository. For these boreholes, substantial amounts of salt would have to be dissolved for any breach of the repository to occur; such dissolution is believed to be very unlikely. One borehole, ERDA 9 (see Figure 1-4), is laterally adjacent to the planned repository and extends approximately 500 feet below the repository horizon. The sealing approach used for this borehole is important in demonstrating waste isolation. All boreholes will be sealed, as appropriate, to meet abandonment requirements. Candidate materials for use in sealing the boreholes include cementitious grout, crushed salt, bentonite, and asphalt.

Crushed salt from the Salado Formation is an ideal long-term seal material because it is expected to be geochemically stable in the Salado environment and because it can be consolidated by host-rock creep closure to a material having a permeability nearly as low as that of the host rock. Predictions of consolidation and the resulting decrease in permeability with time will be based on the following: (1) a constitutive model for crushed salt developed from laboratory data; (2) a creep closure model for host-rock salt; (3) seal locations, sizes, and shapes from designs; (4) and a model that couples consolidation with closure for the sizes, shapes, and locations of the seals. Kinetics models of disturbed-rock-zone fracture healing are also needed to predict overall long-term seal performance. Laboratory and field measurements contribute to reducing uncertainties in models of seal performance.

Short-term-seal materials will be developed and tested to meet stability and performance criteria in the WIPP geochemical and mechanical environments. An understanding of materials and seal components (e.g., curing models for concrete, clay ground-water uptake and swelling, flow through grouted interbeds and hard rocks, and mechanical analyses for rigid seal components stressed by creep of the surrounding host rock) are needed to guide design and evaluate seal performance models. Seal performance models will be adapted for use in performance-assessment calculations.

A detailed conceptual design, in-situ demonstrations of seal emplacement technology, and in-situ demonstrations of initial performance that meets design criteria are necessary to confirm predictions of seal performance.

3.2.2.3 Shafts, Drifts, and Boreholes Seals Designs Activity

Objective

The seal-design program for the WIPP is focused upon addressing scientific and engineering questions related to feasible ways of emplacing high-quality, effective seals that will limit gas or liquid flow through shafts, drifts, and boreholes. Since the seals cannot generally be tested after they are installed in the repository, it is important to evaluate and demonstrate the Quality Control necessary during construction of the seals to assure the required performance of the individual seal components.

The objective of the design work related to the sealing program is to provide validated, detailed designs of the seal components. Detailed designs are required to provide assurance that the proposed seal components can be feasibly emplaced with sufficient quality control to ensure the needed performance. Demonstrations of the feasibility of constructing selected components are planned as part of the validation efforts.

This activity will focus on answering design-related questions, which include the following. What sizes, shapes and numbers of components are needed? Where should the seal components be located? What materials should be used? What methods are preferred for installing the seals? What construction approaches should be taken to limit costs while enhancing seal performance?

Relevance to Compliance

The technical approach for this design effort is iterative. Initial concepts and general criteria were developed and evaluated; an initial reference design was then created for each component. Functions of the individual components are being identified and performance criteria are being developed. Detailed conceptual designs will be developed for each component; construction drawings will be prepared for the components of the large-scale seal tests. Design validation studies will focus on documenting similar construction, on structural analyses of the expected conditions, and on the site-specific demonstrations planned as part of the large-scale testing at WIPP.

Performance evaluations of the seal components, results of development and laboratory testing of sealing materials, and experience gained in the seal tests conducted at WIPP will be considered in the designs. Additional considerations will be derived from structural models of the anhydrite and of the creep behavior of the salt, from disturbed rock zone evaluations, from hydrologic models of the WIPP environment, and from grouting demonstrations.

Both long-term and short-term components are needed in the sealing system. Long-term components are made of salt that will reconsolidate as a result of the creep of the surrounding salt. The design objective is to achieve as high an initial density as practical in the sealing salt. Options include

tamping the salt in place, installing preconsolidated blocks of crushed salt, or using blocks of salt quarried from underground areas at WIPP. The short-term components must function until the sealing salt has reconsolidated to an acceptably low permeability; analyses show this is expected to be no longer than 100 years after emplacement if the salt is emplaced at a sufficient initial density. In panel seals, components will be emplaced soon after the panel is filled with waste; certain of these components must be effective almost immediately after their emplacement to assure that gases are controlled during the repository operations. Principal differences between seal designs for boreholes and for shafts are associated with the requirement for remote emplacement and assessment of the condition of the holes and the need to consider whether or not the borehole casing must be removed, either partially or entirely.

Detailed designs are needed for all seal components to assure emplacement feasibility of the proposed barriers, to evaluate cost-effectiveness of the proposed construction, and to ensure seal performance through the quality of the construction. These designs will be used to develop the models of seal performance that can determine if brine can enter the repository or if unacceptable amounts of brine or gas can flow from the repository.

3.2.2.4 Disturbed-Rock Zone Permeability Activity

Objective

A seal includes emplaced grouts in the disturbed rock zone of surrounding interbeds and hard rocks and, for seals in salt, predictable salt-fracture healing in the surrounding disturbed rock zone. Grouting is being considered for rock surrounding upper shaft seals in the Rustler Formation and for interbeds surrounding seals in the Salado Formation. Salt-fracture healing is critical to the performance of long-term shaft seals.

The objectives of evaluating the disturbed rock zone are to establish the extent of the disturbed rock zone that exists near WIPP underground openings, to assess healing mechanisms, to determine the effectiveness of grouting in the disturbed rock zone, and to develop models to predict the observed behavior of the disturbed rock zone. Models of the disturbed rock zone will be used to evaluate the potential for flow past seal components and to aid in assessing the degree of grouting that may be needed near drift and shaft seals.

Research and modeling of salt-fracture healing will focus on answering the following questions. Will the disturbed rock zone in the host-rock salt surrounding the seals heal with sufficiently low permeability to satisfy seal performance requirements? How long will healing take, and what will be the disturbed rock zone permeability as a function of time?

Research, development, testing, and modeling of properties of the disturbed rock zone in hard rock and interbeds will focus on answering the following questions. How much of the disturbed-rock zone must be grouted? Can grouts and grouting technology be developed to adequately grout the disturbed-rock zone? What will be the permeability of the disturbed rock zone after grouting, as a function of time (i.e., will the disturbed rock zone adequately resist fluid flow after grouting?)?

Relevance to Compliance

The approach to predicting the permeability of the disturbed rock zone in host-rock salt over 10,000 years begins with modeling the ubiquitous microfracture formation in the salt at the seal location. The model is based on possible modes of fracture and on laboratory determination of the parameters describing tertiary creep of salt. Fracturing can progress with time as the salt continues to deform,

but eventually, as seal components take up pressure, the salt can heal existing fractures. Computational models must incorporate the fracture model and address discrete fracture formation. Establishing the relationship between fracture formation and permeability will allow disturbed rock zone permeability to be predicted.

Characterization of the disturbed rock zone in the hard rock and in the interbed will entail numerous measurements of gas flow, changes in the flow over time, and spatial distribution of these flows. Sealing this zone will be addressed by conducting laboratory experiments to develop and characterize grout materials, in-situ testing to develop and demonstrate grout emplacement technology for seals, and modeling to predict the fluid-flow resistance of disturbed rock zones after grouting, as a function of time. Grout materials will be developed that are stable in the WIPP geochemical environment and that can be emplaced in small fractures or pores. Emplacement technology will be developed and demonstrated with small- and large-scale in-situ tests. Models of disturbed-rock-zone permeability after grouting, as a function of time, will be generated and incorporated in sealing system models.

Short- and long-term seals must perform to meet design requirements throughout the required functional life of these seals. Models of flow in the disturbed-rock zone in the Salado are needed for seal-performance models.

Short-term-seal grout materials must be developed and tested to meet stability and performance criteria for WIPP seals. Grouting technology must be developed to limit ground-water and gas flow in pore and fracture systems. Measurements of disturbed-rock-zone performance after grouting are needed to generate seal performance parameters for performance assessment. In-situ testing of grouts is necessary to confirm predictions of seal performance.

3.2.2.5 Shafts, Drifts, and Boreholes Closure Activity

Objective

The closure evaluations will help validate the mechanical behavior of the salt. Laboratory studies and large-scale experiments at the WIPP investigate creep, fracturing, and subsequent healing of the salt. The mechanical models must be coupled with hydrologic flow models to assess coupled flow and deformation effects associated with creep closure of the disposal rooms. The models form the basis for evaluating the performance of structural support systems during the operational period, the short-term (< 100 years) behavior of seal components, and the long-term response of the salt near the disposal rooms or the shafts.

Two fundamental questions about shaft, drift, and borehole closure concern the mechanical response of the salt into which the planned repository is excavated. The answers influence the behavior of the disposal room and its contents, the disturbed rock zone, fractures, and seals. How quickly and completely do vertical and horizontal openings into the underground facility close? How do backfill and fluid pressures affect this closure? Resolution of these questions is critical to the development of several necessary models.

Relevance to Compliance

The approach has been to develop the necessary constitutive model for salt deformation based entirely on laboratory-generated material-properties data. Computational models are developed that accommodate the model, the site stratigraphy, and the specific room, drift, and shaft geometries for use in predicting long-term closure response. Data from a series of in-situ tests will be compared

with the predictions. In addition to the continued collection of data from the initial test rooms and drifts, data are now being collected on the cylindrical shaft and room geometry.

The development of the laboratory creep-response data base is nearly complete. The focus is to define the probability density functions for the creep parameters that are necessary for performance assessment. The Munson-Dawson constitutive model for creep continuum deformation is well developed. For any geometry of underground opening this model predicts the time-dependent creep of salt as a function of the stress and temperature. The principal effort is to simulate the underground room behavior and the response of shafts, as represented by the in-situ test data. These simulations have been or are being extended to the response of a disposal panel. Both open and brine-filled shafts and boreholes have also been simulated for seal development. These simulations of in-situ response will continue because they form the basis for establishing the validity of and confidence in the long-term predictions required for performance assessment and seal design. The predictive technology will simulate the mechanical response of rooms, drifts, and shafts.

Computational model development continues because increasingly sophisticated methods in numerical solution techniques are essential to effectively apply the Munson-Dawson model, to simulate the room-content compaction processes, and for the increasingly large physical mesh models needed to simulate multiple room and panel complexes. The Munson-Dawson model and the computational models also form the basis for developing the fracture model and associated computational model.

The development of a predictive technology to validate structural response is fundamental to the program. Creep closure of underground openings determines the manner and timing of the encapsulation of the waste, the response of the room to pressurization from the formation of gas, and indirectly, the conditions for the inflow of brine to the room. Creep closure is also the driving force for the compaction of crushed salt backfill, for the compaction of the waste, for the stresses on seals, and for the compaction of seal components.

As the technology for describing the response of seals is developed, the continuum model for salt creep and associated computational models will form the basis for characterizing fracturing in the disturbed rock zone.

3.2.2.6 Repository Design Activity

Objective

The design of the WIPP facility has been completed. Most of the surface structures have been constructed and a substantial portion of the underground workings have been excavated. (A brief description of the planned repository is in Section 1.1.2.) The objective of this section is to explain that some characteristics of the facility, as designed and partially constructed, are used in the assessments of compliance. Several of these characteristics are identified here, as are some future decisions related to repository construction or operation that could modify assumptions used in the performance evaluations. It is not anticipated that any additional studies will be performed as part of this Repository Design activity.

Relevance to Compliance

Numerous geometric features of the repository design are used in the performance assessments. Some of these are the lateral extent (footprint) of the repository; the depth of the repository; the number, location, size, and depth of the shafts; the number of waste panels; the sizes, shapes, and

number of storage rooms; the extent of the experimental area; and the distance from storage rooms to various interbeds.

In addition, numerous assumptions are made, based on the current design, related to the expected status of the underground areas from the time of waste emplacement to decommissioning. These assumptions include the expected quantity of waste to be emplaced, that waste will be emplaced in eight panels and in the major access drifts between these panels, that all underground openings will be backfilled, and that conventional rock-bolt support systems will be used in the disposal rooms. Also, the expected conditions of the shafts, drifts, and boreholes at the time of seal installation are important design information. Similarly, the flow rate of air achieved by the ventilation system may be an important parameter in assuring compliance during repository operations with regulations related to VOC release.

While the assumptions and information used in performance evaluations are consistent with current designs and operations, some facility changes that could occur would impact compliance. As part of planning such changes, compliance concerns would be identified and evaluated. An example of a future decision that could impact performance would be changes in roof support in disposal areas, adding significant quantities of metals that could corrode and generate gases.

The repository design and as-built drawings form the basis for performance evaluations. Changes in the performance evaluations related to repository design would be likely only if substantial modifications were made in the construction of the remaining panels or if maintenance operations were to be extensively modified. No additional work in this area is believed necessary, except to ensure that construction and operations-related decisions remain consistent with the assumptions and data used in compliance evaluations. Any changes in design resulting from the decisions on compliance will be evaluated and documented.

3.2.3 Waste Interactions

Three activities are designed to provide information (for assessing compliance with the final disposal regulations) about the waste interactions within the disposal room. The first activity (Section 3.2.3.1 - Gas Generation Characteristics) evaluates the gas generation characteristics of the waste emplaced in WIPP disposal rooms. Gas generation impacts the disposal-room performance and fluid flow (both brine and gas) within various portions of the disposal system. The second activity (Section 3.2.3.2 - Radionuclide Source Term in Disposal-Room Brine) evaluates the concentrations of radionuclides expected in disposal-room brine. These concentrations are used (in conjunction with processes such as those expected within the Culebra Dolomite and a human intrusion borehole) to estimate the total quantity of radionuclides transported from the disposal room to the accessible environment under either undisturbed or human intrusion conditions. The third activity (Section 3.2.3.3 - Waste Characterization) evaluates characterization requirements for the WIPP radionuclide and material inventories for purposes of the disposal regulations. The radionuclide inventory is used in estimating the radionuclides released from the repository under long-term conditions; the material inventory is used in estimating gas generation rates and potentials within the repository. Further detailed discussion of the objectives, technical approach, and rationale of the gas generation programs and radionuclide source-term can be found in the TNAD (DOE, 1992a).

3.2.3.1 Gas-Generation Characteristics Activity

Objective

Gas production caused by the decomposition of cellulosic waste, corrosion of metals, and radiolysis of waste all may impact repository performance. The gas generation, in conjunction with the creep closure and consolidation of the disposal room contents, is the source of driving pressures that may prevent the complete closure of the disposal room, may cause room expansion, may cause migration of gases out of the repository, may cause crack dilation or fracture initiation or both in the interbeds and marker beds, and may drive brine out of the disposal room, thus limiting radionuclide transport by isolating the waste from the brines.

The objective of the gas generation program (GGP) is to develop predictive modeling capability for gas generation species and rates from the date of first emplacement and thereafter throughout the period of regulatory concern. The predictive model must work over a wide variety of materials; i.e., over the range of materials covering the potential repository inventories for the WIPP, over a wide range of chemical environments in the presence or absence of brines, and over a wide range of pressures. The gas generation models will then be either transferred directly or modified as necessary to assess disposal room performance, Salado flow and transport, and total system performance.

Relevance to Compliance

Relationships between various elements of the GGP studies and the performance assessment are illustrated in Figure 3-5. In addition to supporting performance assessment, the information created by the GGP also supports modeling efforts for the disposal-room systems models, fluid transport models for the Salado, and seal performance models. These other models then support performance assessment by supplying additional information. Figure 3-5 shows the relationships between the laboratory studies, TRU mixed waste studies (bin-scale tests), and the gas generation modeling studies. The interface with the rest of the WIPP research, development, and design program (i.e., performance assessment, the disposal room, seals, etc.) and the GGP is the gas generation predictive model.

Based on information acquired from the laboratory GGP, a gas generation numerical model will be created incorporating the appropriate and expected geochemical/waste processes. A bin-scale test program using both simulated and TRU mixed waste will be executed at the WIPP to test sections of the gas generation model. Insights acquired from the bin-scale test program may be further explored in the laboratory before being incorporated in the gas generation numerical model. The gas generation numerical model itself, and/or results from the gas generation model analyses, will be shared with other programs within the WIPP Project that are performing modeling calculations.

In addition to the general logic outlined above, there are some additional tasks shown in Figure 3-5. The studies that comprise the "Characterize Test Wastes" task identified in Figure 3-5 characterize the types and amounts of materials that will be placed in the bins. This information is essential for the gas generation numerical model. Similarly, the studies that comprise the "Characterize Disposal Inventory" task characterize the types and amounts of materials that will be disposed of in the WIPP. This information is also essential for application of the gas generation numerical model to the inventory at large, but it is likely to be collected differently than the information in the bin-test waste characterization process that focuses only on materials that have a significant impact on gas generation.

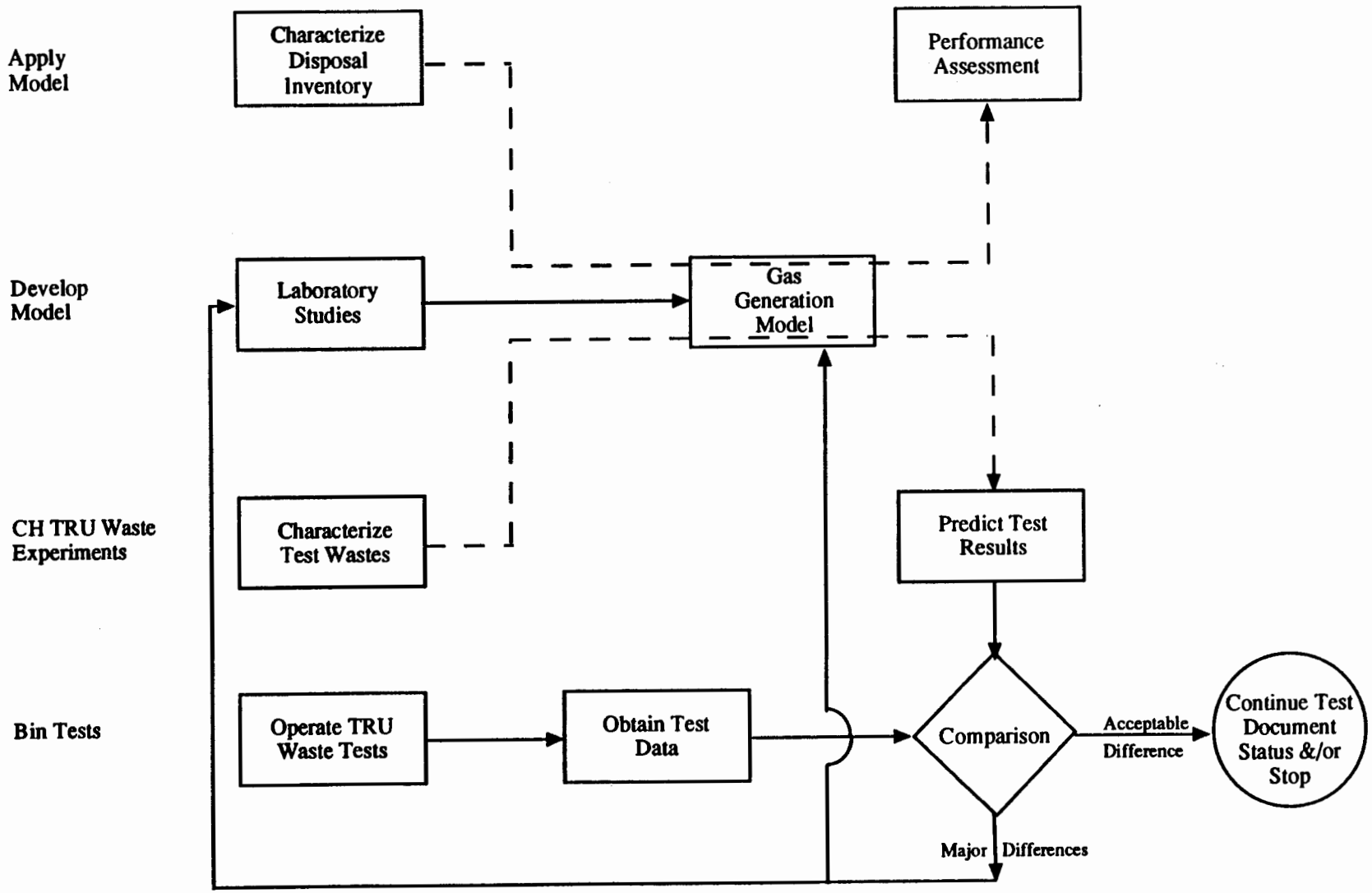

Figure 3-5. Relationships Between Elements of the Gas Generation Program and Performance Assessment.

The gas-generation predictive model will supply information for both performance assessment and supporting modeling efforts such as disposal room performance and fluid flow and transport models. The gas generation model will be developed with data from the existing literature and specific studies in the laboratory gas generation program. As such, it is expected that, as new results from the laboratory program are available, the gas generation model will be updated and improved on a cycle that coincides with and supports performance-assessment calculations. Information from gas generation experiments using TRU mixed waste will improve confidence in the model and identify any areas of the model and lab program that might need improvement. Comparisons of actual gas generated to model predictions will serve to evaluate the predictive capability of the gas generation model and provide evidence that the final gas generation model will predict conservatively.

3.2.3.2 Radionuclide Source Term in Disposal-Room Brine Activity

Objective

The objective of this activity is to provide a model for predicting concentrations of actinide-containing species in disposal-room brine. The principal types of mobile actinide-bearing species in brine are expected to be dissolved ions in several oxidation states, and dissolved complexes of these ions with ligands, colloids, and sorbed solid suspensate. The identities and concentrations of these species are important parameters for the mass transport models for evaluating regulatory compliance. Specifically, the magnitude of retardation of radionuclide transport in brine by sorption onto surfaces of geologic media is species-dependent, and the release quantities depend on the concentrations of radionuclides in the brine solution.

Development of a model for predicting actinide concentrations will be furthered by obtaining answers to the following scientific questions. What would be the concentrations of the actinide-bearing species in brine under the variety of chemical conditions that could exist within the repository and the heterogeneous waste? What would be the oxidation states of the species in brine? What would be the temporal behavior (e.g., changes in concentrations and sizes) of colloids? How do waste constituents and other room contents, including room backfill materials, affect the types of species and their concentrations? In particular, how do ligands originating in the brine and in the waste affect the concentrations of complexes? How does sorption on backfill materials affect radionuclide speciation and concentrations? If the actinide-bearing species reach the Culebra water-bearing zone, what would be their concentrations in the Culebra chemical environment? How are predictions of these parameters for ranges of conditions best embodied in a predictive model for use in performance-assessment calculations? Additional questions may become apparent as the work proceeds.

Relevance to Compliance

The technical approach to addressing these questions consists of conducting laboratory studies and tests with TRU mixed waste and developing predictive models. Laboratory studies of actinide speciation, complexation, solubility, sorption, colloid formation, and other chemical processes are designed to develop required chemical understanding. A conceptual model is developed from laboratory test data and the derived chemical understanding. A quantitative predictive model will be developed from the conceptual model and validated with data from the tests with TRU mixed waste.

Laboratory studies of actinide disposal room chemistry include determination of species (including colloids), stability constants for complexes, solubilities, other chemical equilibria, and sorption properties of transuranics. This effort is supported by inputs on the chemical environments in the disposal rooms obtained from the gas generation studies. These chemical environments are dominated

by the chemical interactions among waste constituents, host rock, gases generated from the waste, and WIPP brines.

An actinide source-term model is being developed to predict the concentrations of mobile actinide-containing species, including colloids, in brine in the disposal room. Model development is based on information from the published literature and data from laboratory studies. Results from the tests with TRU mixed waste will be used to test the validity of the model for predicting actinide concentrations under waste disposal conditions.

The actinide source-term tests with TRU mixed waste, to be conducted at the Los Alamos National Laboratory, are intended to determine species and steady-state concentrations of actinides, complexing agents, and other chemical reactants in containers of wastes inundated with simulated Salado brines. The extent to which the interactions of brine, waste, and backfill additives influence the species and concentrations as a function of time will be determined. Drum-scale tests will be done with highly heterogeneous waste types, such as combustibles and metals. Liter-scale tests will be done with more homogeneous waste types such as sludges and pyro-chemical salts. Actinides will be added to ensure that actinide concentrations in the brine will be adequate for successful tests. The test system and conditions will be chosen to measure pertinent variables for testing the validity of the actinide source term. Headspace gas data will be used to track the progress of chemical and microbial processes in order to determine whether expected processes such as ligand generation are occurring during the time of the tests. These gas data are not appropriate as indicators of gas generation rates for TRU mixed waste, because test conditions will not be representative of WIPP disposal conditions.

Concentrations of actinide-bearing species in waste room brine are sensitive parameters for performance-assessment calculations. Preliminary performance assessments have shown that concentrations of isotopes of the actinide elements in WIPP brine are important parameters for evaluating compliance with the disposal regulations. The current concentration estimates for species of these actinide elements are in ranges spanning nine orders of magnitude, and it has been shown that the highest concentrations could impact the outcome of performance assessment. Species identity, including colloids, is important for the prediction of actinide mobility. An actinide source-term model is designed to provide concentration and species predictions.

Information from laboratory studies is needed to develop an actinide source-term model. Laboratory studies are designed to elucidate and quantify the complex chemical behavior of actinides, including colloid formation. Sensitivities to parameters such as Eh, pH, and the concentrations of organic and inorganic ligands that could act as complexing agents are included. Information from laboratory studies is also needed to aid in the interpretation of results from actinide source-term tests with TRU mixed waste.

Data from these tests are needed to test the validity of the actinide source-term model. These TRU mixed waste tests differ from the bin-scale tests in that the test matrix is designed to isolate chemically relevant waste variables that influence actinide concentrations in brine rather than gas generation rates. To this end, mass transport control of rates is suppressed by conducting the tests in brine-filled test containers and agitating the contents to ensure immersion and mixing of all waste materials and brine.

3.2.3.3 Waste Characterization Activity

Objective

Information regarding the quantities and compositions of the inventories of both existing and to-be-generated TRU wastes and TRU mixed wastes is essential. Characterization of the existing waste inventories within the DOE system must be adequate to define the variability of the radionuclide content. However, the characterization must also be adequate to define the inventory-scale variability in other waste-related parameters of interest in long-term repository performance, such as gas generation potentials, general mechanical properties, and factors possibly affecting the concentrations of radionuclides in brine. Characterization of existing inventories alone is not sufficient. In order to define a realistic range of final WIPP inventories for use in evaluation of regulatory compliance, the possible ranges of both inventories and characteristics of to-be-generated wastes will be estimated. Characterization of both existing and to-be-generated waste inventories must, in combination with detailed characterization of experimental wastes, TRU mixed waste experiments, numerical modeling, and inventory estimates, be sufficient to define the actinide source term under a realistic range of possible long-term repository conditions.

Relevance to Compliance

The technical approach to characterization of the inventories of CH TRU and RH TRU wastes has essentially been divided into two distinct programs. One program is to obtain DOE-system-wide data concerning the existing inventories of TRU wastes and TRU mixed wastes. This effort is described in the *Waste Characterization Program Plan* (DOE, 1992c). A second program is ongoing to define the range of possible characteristics and inventories of to-be-generated wastes (DOE, 1992b). This effort considers both weapons-production wastes and wastes expected to result from decontamination and decommissioning of DOE facilities.

The existing waste inventory characterization employs detailed characterization methods, such as real-time radiography to inspect drum contents and to estimate the abundance of various matrix materials, and passive-active neutron analysis to determine contents of both plutonium and other major radionuclides. Not every waste container must be characterized. Instead, the program is intended to examine enough TRU mixed wastes at the various DOE facilities to provide a statistical basis from which to estimate the total variability of the existing waste inventories. The expectation is that the gas generation and actinide-source-term models will be used to investigate the effects of inventory uncertainties after confirming the models by comparison with the performance of carefully characterized experimental wastes. Therefore, the level of detail required in the at-large characterization of existing wastes is not expected to be as great as that for experimental wastes.

However, no sampling approach applied to existing wastes can estimate the variability of to-be-generated wastes. Therefore, a second program is required that documents the expected ranges of inventories and characteristics of to-be-generated wastes. The existing documentation from this effort is contained in *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE, 1992b). For purposes of performance assessment, the estimated variability of the final WIPP waste inventory will be some combination of the measured variability of existing wastes and the forecast variability of to-be-generated wastes. The ultimate objective is to define realistic ranges of variability of the final WIPP waste inventory. Understanding variability will ensure that the range of inventories considered for performance assessment is adequate for regulatory evaluation, and that the gas generation and actinide source-term models are capable of describing the behavior of the estimated range of inventories.

Waste characterization information is needed for gas generation modeling, source-term modeling, and performance-assessment modeling of the planned WIPP repository. The at-large characterization of existing inventories is needed to estimate the variability of the existing wastes. This characterization need not be carried out to a greater level of detail than is required for regulatory compliance or is achievable for estimates of the variability of to-be-generated wastes expected to be in the final WIPP inventory; otherwise, the uncertainty in characterization of existing wastes would be exceeded by the uncertainty in the to-be-generated inventory. The range of final inventories considered must be adequate for regulatory purposes. Only if this condition is met and agreed to by the regulator could the gas generation, actinide-source-term, and performance-assessment models be adequate and internally consistent for evaluation of long-term performance.

3.2.4 Human Intrusion

The EPA gives specific guidance for considering inadvertent human intrusion in Appendix C (formerly Appendix B) of 40 CFR Part 191. The EPA assumes that exploratory drilling for resources is the most severe intrusion that must be considered (EPA, 1985c). Determining the probability of intrusion poses questions that cannot be answered by numerical modeling or experimentation. Projecting future drilling intrusions requires knowledge about complex variables such as economic demand for natural resources, institutional control over the site, public awareness of radiation hazards, and changes in exploration technology. Extrapolating current trends 10,000 years into the future requires expert judgment.

Given that an intrusion occurs, the effects of the intrusion must be considered. The intrusion event is characterized by the drilling of a borehole, with removal of drill cuttings and eroded material along with any additional materials that may become entrained in the drilling fluid. Processes set in motion by the drilling can include injection of gas and brine from an underlying brine reservoir into the repository and injection of gas and brine from the repository into the overlying formations, principally the Culebra Dolomite Member of the Rustler Formation. The characteristics of the borehole itself are included in the modeling.

Information needed includes the rate of future intrusions and the amount of cuttings, cavings, and collapsed material that are released directly to the surface during the intrusion event. If transport in the Culebra is governed by double-porosity flow, the direct release to the surface dominates the total release because the transport process through the Culebra delays and limits the releases along that pathway. If transport in the Culebra is governed by single-porosity, fracture-only flow, subsurface release through the Culebra could dominate direct releases, depending on the properties of the intruding borehole.

The Repository Design and Engineered Barriers activity (Section 3.2.2) , the Waste Interactions activity (Section 3.2.3), the Salado Hydrologic Properties and Transport Properties activities (Sections 3.2.1.3 and 3.2.1.4) and the Site Characteristics activity (Section 3.2.1.5) support the development of performance-assessment models needed for describing both undisturbed and human intrusion scenarios. Non-Salado Hydrologic and Transport Properties activities (Sections 3.2.1.1 and 3.2.1.2) are exclusively directed towards human intrusion scenarios, as are the remaining activities described in this section.

3.2.4.1 Human Intrusion Modeling Activity

Objective

Thus far, human intrusion scenarios are the only scenarios for which preliminary performance-assessment calculations have predicted releases to the accessible environment in the 10,000 years after waste disposal. Some of these scenarios include a borehole drilled through the repository and the Salado Formation into a pressurized brine pocket in the Castile Formation that may partially extend beneath the repository. Thus, performance-assessment models must predict the behavior of a pressurized brine pocket beneath the repository and the transport of materials from the repository, up the breach borehole to the surface (in the case of drill cuttings) or laterally through the units overlying the Salado, primarily through the Culebra, to the accessible environment. Flow and transport in the Culebra may be altered by brine and gas from either the Castile brine pocket or the repository being injected into the Culebra.

The location and flow characteristics of brine pockets in the Castile Formation are important in modeling inadvertent drilling intrusions through the repository and into an underlying brine pocket. Because geophysical information suggests that pressurized brine may underlay at least a portion of the waste panel area, the WIPP SEIS (DOE, 1990b) and subsequent performance-assessment calculations have conservatively assumed that a brine pocket underlays all of the waste panel area. The brine pocket provides significant enough quantities of brine under pressure to increase transport of fluid from the repository into the Culebra. Questions of interest are: What would flow rates into the breach borehole be if a brine pocket were penetrated? How rapidly would the flow rates decrease in time? How would partial desaturation of the Culebra along the flow path affect flow and transport in the Culebra?

Relevance to Compliance

In the event that the repository is breached by human intrusion, brine, gas, and radionuclides could be transported up the breach borehole and released into the Culebra. Current modeling of flow and transport in the Culebra assumes saturated flow conditions and neglects the influence of gas. However, gas discharged up the borehole could significantly alter the flow and transport characteristics. The large volume of the gas expected to be discharged up the borehole may cause flow velocities different from those calculated assuming saturated flow. The sources of the gas would be gas that is known to occur with and be dissolved in the Castile brine and free gas generated from the wastes in the repository. These gases could cause unsaturated conditions in the Culebra if injected into the Culebra as a result of human intrusion. Transport model development will consider the effect of unsaturated conditions. Transport characteristics of the Culebra, including retardation, may change from saturated conditions to unsaturated conditions because of different flow velocities and different chemical conditions associated with injected gas. Changes in the flow velocities and transport characteristics could have a significant effect on the transport pathway, travel time, and retardation in the Culebra.

Brine and gas is expected to be discharged into the Culebra if human intrusion occurs. The development of unsaturated conditions may have appreciable effect on the flow out the borehole and to the site boundary. In addition, the transport in the Culebra may be affected by smaller residence times resulting from faster flow and by changes is chemical conditions. Therefore, the effect of gas and brine discharging into the Culebra from a human intrusion scenario should be evaluated.

Existing site characterization data include information gained from testing in WIPP-12 and ERDA-9 and geophysical surveys. WIPP-12 was drilled about 1 mile north of ERDA-9 (see Figure 1-4). The

borehole intercepted a Castile brine reservoir. Interpretations of WIPP-12 data were completed and documented. A series of brine-reservoir-breach calculations, with sensitivity studies and detailed modeling of the brine reservoir, were performed for the WIPP SEIS (DOE, 1990b) and details were reported in subsequent publications. The calculations showed that the analytic model currently used for performance calculations to describe the brine reservoir is an excellent approximation to the more detailed model, thus verifying the brine reservoir model used by performance assessment against the detailed, calibrated model. No additional modeling or testing are planned for Castile brine reservoir characterization. Performance-assessment sensitivity studies performed in 1989, 1990, and 1991 indicate that remaining uncertainties in Castile brine reservoir characteristics do not significantly affect the results of the performance assessment for the disposal regulations.

3.2.4.2 Probability of Human Intrusion Activity

Objective

All performance-assessment calculations to date indicate that only human intrusion scenarios (exploratory drilling) contribute to the cumulative releases to the accessible environment in the 10,000 years after waste disposal. Research addresses the following questions. What might be the possible future states of society and how might these contribute to intrusions of the repository? How can the question of the probability over time that future societies might inadvertently intrude upon the WIPP be addressed in a systematic fashion? Which systems of markers and protective barriers might deter inadvertent human intrusion, given the possible states of society? What type of records system might be able to convey the appropriate information to the potential intruder in a timely fashion to deter intrusion? To what extent might markers, protective barriers, and records reduce the probability over time of inadvertent human intrusion?

Relevance to Compliance

The technical approach to addressing direct human impacts is to convene expert panels, each responsible for a specific aspect of the topic. Expert panels have addressed protective barriers and records systems. Additional study is required to design the specific markers and the appropriate messages. The rationale for using expert panels is that human intrusion cannot be addressed through normal experimental procedures. The topic requires a multidisciplinary approach, where potential solutions are filtered through the constraints and contributions of all the represented disciplines. For example, the question of potential marker systems (design, materials, arrangement, graphics, communication, etc.) must be addressed by a multidisciplinary group.

The current probability model for human intrusion is based on the assumption that future episodes of exploratory drilling can be represented by a Poisson process with either a constant, but imprecisely known, intensity of drilling or an intensity of drilling that varies with time. The first case was selected as an example model to judge the effect of multiple intrusions (SNL, 1991). The second case allows the information elicited from the expert panels to be incorporated into the performance assessment (SNL, 1992). The construction of the time-varying intensity functions requires probabilities for levels of technology for selected possible future societies; for selected time intervals, probabilities that passive marker systems are extant given the level of technology; and for each time interval, probabilities that the marker systems deter human intrusion given that markers are extant and given the level of technology. These probabilities have been produced by the expert panel on possible future societies and passive marker systems. Additional probabilities needed are probabilities that barrier systems are extant for each time interval and that the barrier system prevents human intrusion given that it is extant and given the level of technology. These probabilities will be the focus of a planned expert panel on barrier systems. The final choice of an approach to constructing the drilling

intensity function, either constant or time-varying, will depend on future interactions with reviewers or expert panels, or both, such as the panel on barrier systems for preventing intrusions.

3.2.4.3 Cuttings Release Parameters Activity

Objective

The objectives of this activity are to provide an experimental basis for modeling entrainment of drill cuttings, and if necessary, modify the existing model to agree with the data. Drill cuttings entrained in the drilling fluid during a human intrusion of the WIPP repository would be carried to the surface, releasing radioactive material (along with intentionally removed core material). The amount of radioactive material released in cuttings would depend on the volume of waste removed. For waste forms with low material strength, material adjacent to the borehole wall might erode into the hole, because of scouring by the drill fluid. Rapid release of entrapped gases from relatively impermeable waste forms might also cause collapse of material into the borehole. Under both circumstances, the expulsion of waste would enlarge the borehole diameter. A greater volume of waste would be removed than expected on the basis of the initial borehole diameter alone. How TRU mixed wastes are likely to be altered by biological and chemical processes as a function of time, what effects these changes are likely to have on the strengths and permeabilities of the various waste forms, and how these changes, in turn, will impact the amount of material brought to the surface as a result of drilling into the repository must be examined.

Relevance to Compliance

Mathematical methods for estimating the amount of cuttings entrained in drilling fluids during a drilling into the repository are well developed, and have been used to identify material properties critical to this problem (SNL, 1991). Experimental methods of determining these material properties have also been defined. However, none of the experimental methods have been applied to surrogate waste materials to date. As a result, the current estimates of cuttings releases are uncertain.

The technical approach for examining borehole erosion has two parts. First, to evaluate borehole erosion, material properties from laboratory tests on surrogate waste materials, the properties of which bound those of degraded TRU mixed wastes, will be obtained. These properties will then be used to improve the confidence in predictions of borehole erosion in response to human intrusion. Second, the borehole-enlargement model will be refined, and the model's reliability will be evaluated through laboratory experiments.

Radioactive releases because of the removal of cuttings of TRU mixed waste from a borehole during human intrusion is currently one of the dominating processes in preliminary performance assessments for the containment requirements (see SNL, 1991). The current estimates of cuttings releases indicate that erosion is the dominant mechanism (other than direct removal of core). Values of the properties for estimating borehole erosion are based on current technology and drilling practices, rather than on any WIPP-specific experiments. The possible role of hole-wall collapse from release of trapped gases is largely undefined, and relevant material properties are assumed in the absence of data. Because of the impact of cuttings release on the effects of human intrusion, an increased understanding of both borehole erosion and possible borehole-collapse effects would significantly decrease the current uncertainties in human intrusion effects on long-term repository performance.

Information needed about possible future intrusion boreholes includes (1) initial conditions after abandonment, such as casing, plug locations, and plug permeabilities, and (2) long-term (10,000-year) conditions for plug life, degraded plug and borehole-debris permeabilities, and borehole deformation.

Borehole deformation within the Salado is simulated. The other information needed is obtained from drilling technology and past history from the Delaware Basin.

Chapter 4

Compliance Program for the Resource Conservation and Recovery Act

4. COMPLIANCE PROGRAM FOR THE RESOURCE CONSERVATION AND RECOVERY ACT

The WIPP Land Withdrawal Act requires that this Test Phase Plan address testing relevant to demonstrating compliance with the SWDA as implemented under the RCRA. The DOE is pursuing a compliance program to meet the requirements of EPA regulations 40 CFR 268.6 and 40 CFR 264, Subpart X. The plans for demonstrating compliance with these two RCRA regulations are addressed in this chapter.

The DOE's program for compliance with the requirements of 40 CFR 268.6 consists of four general components:

Ongoing activities to comply with the conditions and limitations of the no-migration determination for the test phase, including waste characterization activities.

A performance assessment to predict the potential for hazardous constituents to escape from the waste management unit over the long term. This assessment focuses on the transport of hazardous chemical constituents through the Salado Formation after the planned repository has been sealed and backfilled.

An assessment to predict the potential for hazardous constituents to reach the unit boundary over the short term. This assessment focuses on the movement of hazardous chemical constituents through the underground ventilation air stream during the disposal and decommissioning phases.

The development and implementation of programs to monitor the performance of the WIPP in a manner that will detect the migration of hazardous constituents at the earliest practicable time.

In contrast, the DOE's program for compliance with the requirements of 40 CFR 264, Subpart X consists of the following components:

The implementation of programs and activities necessary to comply with DOE commitments made in the current WIPP RCRA permit application. These commitments pertain to actions that need to be taken to ensure that the WIPP will be operated in a manner that will protect human health and the environment during the test phase.

The performance of analyses to evaluate human health and environmental effects of the management of TRU mixed waste at the WIPP during the disposal, decommissioning and post-decommissioning phases of the project. The objective of this work is to evaluate whether the facility can be operated in compliance with the environmental performance standard of 40 CFR 264, Subpart X. The standard requires that the WIPP facility be located, designed, constructed, operated, maintained and closed in a manner that will ensure protection of human health and the environment. Where appropriate, these analyses will evaluate potential hazardous chemical exposures to human and environmental receptors. The pathway of concern during the disposal and decommissioning phases is airborne transport from the WIPP underground. As such, this work is similar to that performed to evaluate compliance with the 40 CFR 268.6 no-migration standard during the short term. The relevant time spans of concern for 40 CFR 268.6 and 40 CFR 264, Subpart X are shown in Figure 1-7.

The development and implementation of programs to ensure that the WIPP may be operated safely and in full compliance with 40 CFR 264, Subpart X requirements during the disposal, decommissioning, and post-decommissioning phases of the project.

This chapter describes the DOE's approach for evaluating the ability of the WIPP to be operated in compliance with the 40 CFR 268.6 no-migration standard during the long term and the short term. DOE plans for the evaluation of the ability of the facility to be operated in compliance with the 40 CFR 264, Subpart X environmental performance standard are also described. Activities to support the compliance evaluations are also presented, including descriptions of the relevance of each activity to the evaluations of compliance.

4.1 COMPLIANCE APPROACH FOR THE LONG-TERM PERFORMANCE REQUIREMENTS OF 40 CFR 268.6

The DOE is performing activities to support a petition for a no-migration determination for the disposal, decommissioning, and post-decommissioning phases of the WIPP. The basis for these activities is 40 CFR 268.6, the EPA's guidance on no-migration petitioning (EPA, 1992), and the no-migration determination for the WIPP test phase (EPA, 1990a) (including the EPA's background information document which is in the EPA's docket F-90-NMWP-FFFFF for the NMD for the test phase). The petition will address compliance with the no-migration standard during both the long term and the short term. This section describes the items shown in the "Compliance Approach" column on Figure 2-2.

In the context of this Chapter, "short term" refers to the test, disposal, and decommissioning phases of the project and, in regard to 40 CFR 264, Subpart X, a period of 30 years after the completion of decommissioning. "Long term" refers to the time after decommissioning. Simulation modeling of the long-term performance of the repository to assess compliance with regulatory requirements is generally extended for a 10,000-year period after decommissioning.

The DOE's approach to the evaluation of long-term compliance with the no-migration standard is illustrated in Figure 4-1. This process for evaluating compliance involves collection of pertinent information, assimilation of this information into computer modeling studies simulating the long-term performance of the repository, peer review, review and discussion of the modeling activities and conclusions with regulators, and documentation of the results in a no-migration variance petition. This is similar to the process described in the test phase *No-Migration Variance Petition* (DOE, 1989). The assessment of the ability of the planned repository to comply with the no-migration standard is called the performance assessment.

4.1.1 Performance Assessment

The objective of the 40 CFR 268.6 performance-assessment program is to evaluate whether the WIPP will meet the no-migration standard in the long term. To achieve this objective, the DOE will characterize background quality of air, water, and soil and will thoroughly assess features of the repository that are important to waste isolation, including natural and engineered barriers, the design of the repository and its shafts, and the characteristics of the transuranic mixed waste to be emplaced, including any potential waste interactions, reactions, or transformation or degradation products. In addition, computer modeling will be used to simulate the migration, if any, of hazardous waste constituents from the disposal unit over 10,000 years. In the context of 40 CFR 268.6, "migration" means the movement of hazardous constituents beyond the boundary of the hazardous waste management unit in concentrations exceeding health-based levels. The results of the modeling will be compared with established regulatory standards, which are expressed as concentrations of hazardous

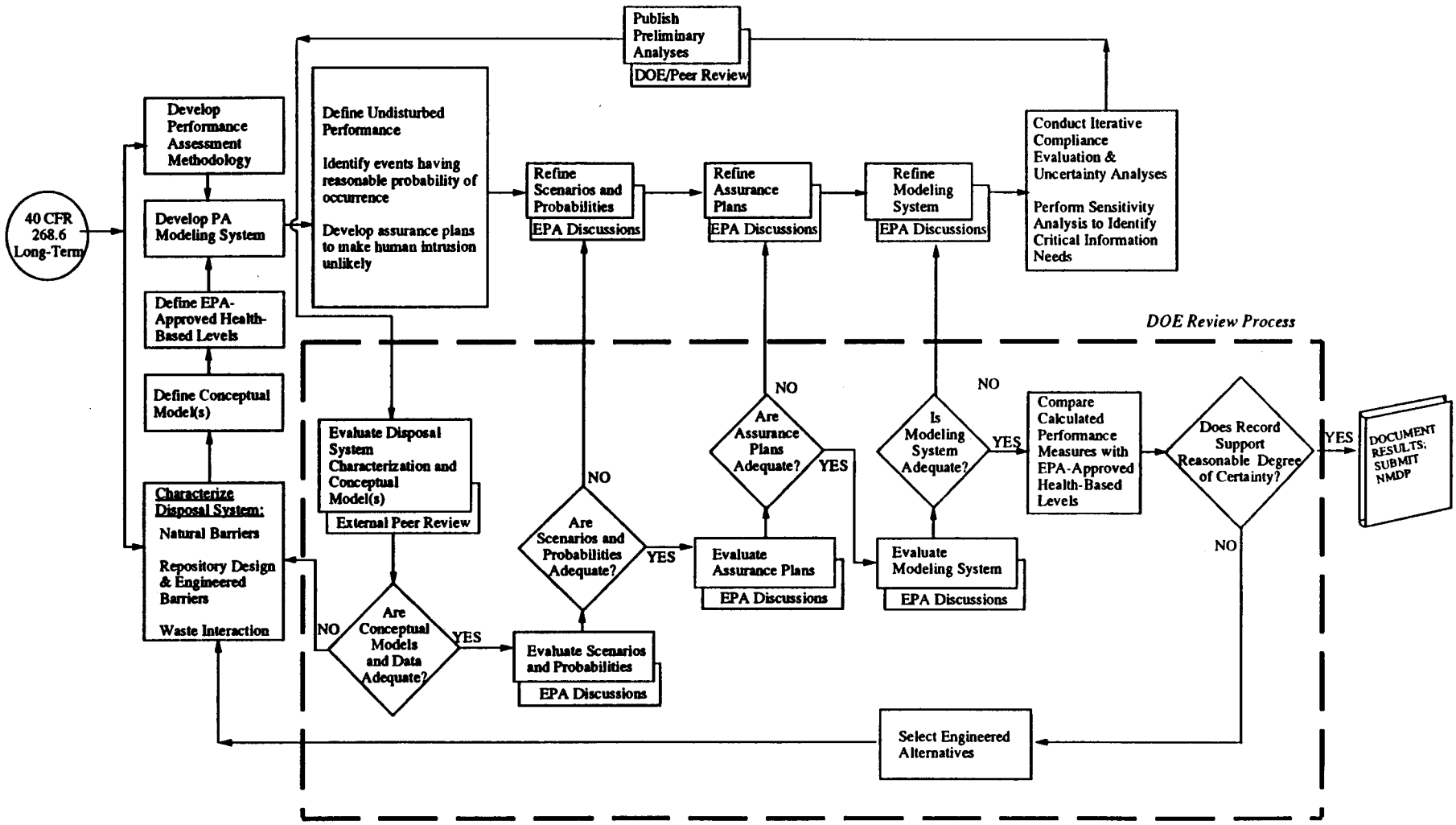

Figure 4-1. Performance-Assessment Approach for 40 CFR 268.6 Compliance Program. The DOE review process is highlighted.

constituents in air, water, and soil. These comparisons will support an EPA determination of whether there is a reasonable degree of certainty that transuranic mixed waste can be emplaced in the WIPP underground without violating the 40 CFR 268.6 no-migration standard.

During the long-term, it is possible that hazardous constituents could be transported through the engineered and natural barriers at the WIPP site. Assessing the likelihood of transport of contaminated gases and fluids over time is central to the determination of compliance with the no-migration standard.

In several respects, the 40 CFR 268.6 modeling program for long-term performance is similar to the modeling program for the disposal regulations (see Chapter 3). Both programs are evaluating the behavior of the waste, the performance of the repository, and the effectiveness of engineered and natural barriers in isolating the waste. Because of these similarities, the 40 CFR 268.6 modeling program is drawing, to the extent relevant and appropriate, from work performed to support the program for the disposal regulations.

4.1.1.1 Models

Characterization of the disposal system has identified processes and events that must be considered when evaluating the potential for hazardous constituents to migrate. The conceptual model refers to the performance and behavior of the repository system, including the natural barriers, the repository design, the engineered barriers, and the waste. The development of this conceptual model permits the selection of a sequence of processes and events that will be subject to the modeling demonstration.

The conceptual model of the behavior of the repository has been developed and mathematical and computational models, simulating the performance of the repository, are being screened. If no existing model is adequate, a new model may be developed. Uncertainties associated with this analysis will be evaluated and documented.

In general, the long-term 40 CFR 268.6 modeling program consists of the following elements:

Develop the conceptual model;
Define processes and events that may affect waste migration;
Screen, assess, and select models;
Select and assess scenarios for analyses;
Perform modeling analysis;
Document models, assumptions, and parameter values;
Determine EPA-approved health-based levels; and
Compare modeling results against health-based levels.

This process is generally similar to that described in Section 3.1.1 for demonstrating compliance with the requirements of the disposal regulations (40 CFR 191, Subparts B and C). The process for the assessment and selection of scenarios for analyses is similar to that described in Section 3.1.1.1.

Initial modeling results will be compared to health-based levels. The no-migration modeling will focus on the specific hazardous constituents present in the transuranic mixed waste. These "indicator chemicals" will be selected on the basis of their prevalence in the waste inventory. The appropriate health-based level for each indicator chemical will be identified for each appropriate environmental medium. The comparison of the modeling results against the health-based levels will support the evaluation of the potential for the WIPP to isolate transuranic mixed waste in compliance with the 40

CFR 268.6 no-migration standard. If results indicate compliance, this finding will be documented in the no-migration variance petition. This petition will be submitted to the EPA for approval.

If noncompliance is indicated, models, assumptions, and parameter values will be reevaluated, and sensitivity studies will be performed to identify critical assumptions and parameters. These will be assessed to determine whether overly conservative values have been used (EPA's guidance (EPA, 1992) states that "reasonably conservative" assumptions should be used.). If this is the case, the modeling approach will be revised. If it is concluded that assumptions and values are realistic, engineered alternatives (including treatment of TRU mixed wastes to meet 40 CFR Part 268 treatment standards) will be evaluated and selected.

The EPA requires that simulation models be accurate and appropriate for the waste constituents considered and that all reasonable pathways to the unit boundary be examined. Models will address the transport of hazardous constituents taking into account the performance of natural and engineered barriers. Models, input data, and relevant documentation should be available for the EPA without restriction.

The regulatory language suggests that knowledge of the concentrations of hazardous constituents at the unit boundary is essential to a no-migration determination. In the case of the long-term performance of the WIPP facility, however, there may be no potential for contaminated gases or liquids moving through rock to reach the unit boundary within the 10,000-year modeling period. This may be the result of insufficient volume of contaminated gases or liquids, insufficient pressure gradients, low flow-path permeabilities and hydraulic conductivities, or high flow-path pore pressures. There will be no need to analyze constituent concentrations, unless it is demonstrated that gases and liquids will reach the unit boundary.

The modeling program will account for all processes important to transport of hazardous constituents in calculating the concentrations of these constituents at the unit boundary. These processes include two-phase (gas and brine) flow, the generation of gas in the waste-emplacement rooms, salt creep, fracturing (if gas pressures are high enough), as well as any waste transformations and interactions with pathway materials.

In its guidance to no-migration petitioners, the EPA states that sensitivity analyses should be used to determine which model parameters are most important. Sensitivity analyses will be performed to identify the parameters that have the greatest effect on the evaluation of compliance. These parameters will be closely examined, and additional literature searches, laboratory experiments, or field testing will be performed, if necessary, to increase confidence in the parameter values.

In addition, the following quality-assurance and quality-control information is required by the EPA (EPA, 1992) for each model used:

Model confirmation and calibration. Simulation models must be calibrated for the specific waste and site conditions and verified for accuracy by comparison with actual measurements.

Justification of assumptions. All assumptions must be properly justified. Reasonable conservatism must be demonstrated.

Assessment of model accuracy. The DOE must demonstrate that the model reasonably represents the actual physical system, that there are no computational errors in the computer code, and that there is a high degree of correlation between the model and measured data (EPA, 1992).

Sensitivity tests. The models chosen should be those that are most affected by the most important parameters.

The DOE will demonstrate the appropriateness of the model and the accuracy of the results. The 40 CFR 268.6 modeling will draw on the results of the gas generation studies and other studies performed during the test phase. Specifically, the results of the following activities will be germane to the modeling: Salado Hydrologic Properties; Salado Transport; Site Characteristics; Disposal Room Performance; Shaft, Drift, and Borehole Seals Performance; Shaft, Drift, and Borehole Seals Designs; Disturbed Rock Zone Permeability; Shaft, Drift, and Borehole Closure; RCRA Constituents Source Term in Disposal Room Brine and Gas; Gas Generation Characteristics; and Waste Characterization.

4.1.1.2 Health-Based Levels

In regard to 40 CFR 268.6, "migration of hazardous constituents" has been defined as the movement beyond the unit boundary of hazardous constituents in concentrations exceeding EPA-approved health-based levels for air, water, and soil. For each indicator chemical subject to the no-migration modeling demonstration, health-based levels will be identified for each appropriate environmental medium.

The definition of health-based levels will require the resolution of regulatory questions including: What indicator chemicals should be evaluated in the modeling program? In addition to air, what are the appropriate environmental media for evaluation of migration of hazardous constituents from the repository (i.e., water or soil)? In the absence of established EPA-approved levels, what are the appropriate levels?

Indicator chemicals will be selected through the evaluation of existing TRU mixed waste characterization information. EPA documentation will be reviewed for established levels for indicator chemicals. In accordance with EPA guidance (EPA, 1992), if health-based criteria do not exist for a hazardous constituent, the DOE may propose a health-based level, using the toxicity testing guidelines contained in 40 CFR Parts 797 and 798 and the EPA guidelines for assessing health risks (EPA, 1986a, 1986b, 1986c, 1986d, and 1986e). If no health-based level can be determined for a constituent, the concentration of that constituent must not exceed analytical detection limits. Use of the analytical detection limits should be based on methods prescribed in EPA publication SW-846 (EPA, 1982). In this case, the lowest possible detection level indicated in SW-846 for each hazardous constituent will be the health-based level (EPA, 1992).

The DOE will develop a technical position addressing the question of the appropriate environmental matrices to be considered for the no-migration evaluation. Since existing health-based levels apply to air, water, and soil, it is not clear which of these levels, if any, should be applied in the case of the WIPP, a unit whose boundary may be deep below the surface in undisturbed rock. Furthermore, if the unit boundary is determined to be at a subsurface location in undisturbed rock, there will likely be no credible pathway for exposure to human or environmental receptors. DOE's proposed approach to these questions will be discussed with the regulatory agency.

4.1.1.3 Uncertainty Analysis

The regulations on no-migration petitioning specify that . . . "[A]n analysis must be performed to identify and quantify any aspects of the demonstration that contribute significantly to uncertainty. This analysis must include an evaluation of the consequences of predictable future events, including, but not limited to, earthquakes, floods, severe storm events, droughts, or other natural phenomena" (40 CFR 268.6(b)(5)).

EPA guidance (EPA, 1992) specifies that the potential for the occurrence of various "infrequent" events during the period that the waste remains hazardous be examined. The "[P]otential impacts and consequences of events with a reasonable probability of occurring . . . should then be estimated with respect to the facility's ability to isolate wastes from the environment. In addition, likely human-induced events which may affect the isolation capability of the unit . . . should be generally considered."

The question of future human intrusion into the repository will be subject to uncertainty analysis. The DOE will apply the "reasonable probability of occurring" criterion based on the use of active and passive institutional controls. This is consistent with the approach described in the following EPA statement which appears in the final no-migration determination for the WIPP test phase (EPA, 1990a): ". . . EPA believes that, in the context of RCRA no-migration decisions, it should address the question of human intrusion by considering the likelihood of the intrusion, and imposing controls to make such intrusions unlikely." The consideration of institutional controls to satisfy the assurance requirements of 40 CFR 191.14 will be important to this evaluation of uncertainty.

This approach may lead to the conclusion that the probability of human intrusion is sufficiently low so that the modeling demonstration may be based on the assumption that it does not occur. The use of controls to deter inadvertent human intrusion are required by 40 CFR 191.14, although EPA guidance to 40 CFR 191.13 specifies that the probability of the occurrence of human intrusion may not be reduced to zero for the performance assessment.

The EPA has specified that the assessment of uncertainty caused by the occurrence of predictable natural and man-induced events consider events that could apply directly to the repository and events that are more regional in nature. The guidance (EPA, 1992) cites seismic events as an example. The guidance states that . . . "[I]n analyzing the potential consequences of predictable phenomena, probable worst-case scenarios should be used to ensure that any errors occur on the side of safety."

The DOE's general approach to the performance of uncertainty analyses for 40 CFR 268.6 is described in the *No-Migration Variance Petition* (DOE, 1989) for the test phase. This approach will be generally pursued for evaluating compliance with the 40 CFR 268.6 no-migration standard in the long term. Sensitivity analysis will also be performed to evaluate the relative importance of various modeling assumptions and parameters.

4.1.1.4 Interfaces with Research, Development, and Design Activities

Similar to the process described in Section 3.1.1.8, an interface function provides feedback to the performance assessment for the long-term 40 CFR 268.6 compliance analyses. This interface links the research, development, and design activities to the ongoing performance assessment.

4.1.2 Monitoring Program

The EPA requires that a petition for a no-migration determination include a monitoring plan to detect migration at the earliest practicable time (40 CFR 268.6(a)(4)). In addition, the regulations provide specific requirements (40 CFR 268.6(c)(1)) through (5)) for the monitoring plan, including requirements for specific information about (1) the media monitored; (2) the type of monitoring conducted at the unit; (3) the location of the monitoring stations; (4) the frequency of monitoring at each station; (5) the specific hazardous constituents to be monitored; (6) the implementation schedule for the monitoring program; (7) the equipment used at the monitoring stations; (8) the sampling and analytical techniques employed; and (9) the procedures for data recording and reporting.

The monitoring program must meet the following criteria:

- All sampling, testing, and analytical data must be approved by the EPA and the data must be accurate and reproducible (40 CFR 268.6(c)(5)(i)).
- All estimation and monitoring techniques must be approved by the EPA (40 CFR 268.6(c)(5)(ii)).
- A quality-assurance and quality-control plan addressing all aspects of the monitoring program must be provided to, and approved by, the EPA (40 CFR 268.6(c)(5)(iii)).

Where applicable, the monitoring program must be in place for a period of time specified by the EPA before any transuranic mixed waste can be received at the WIPP facility (40 CFR 268.6(c)(2)). In addition, the monitoring data must be sent to the EPA according to a format and schedule specified and approved in the monitoring plan (40 CFR 268.6(c)(3)).

Long-term monitoring may address facility performance, as opposed to the migration of specific hazardous constituents. Such monitoring must be meaningful in that it must concentrate on parameters that can be detected in a relatively short time. It is also important that any monitoring program implemented not compromise the capability of the planned repository to isolate transuranic mixed waste.

Long-term monitoring plans will be integrated with plans for complying with the monitoring requirements of 40 CFR 191.14 (assurance requirements). The extent to which these requirements are to be implemented will depend on their efficacy in addressing uncertainty in the modeling. In most cases, hazardous-waste containment and radionuclide containment benefit equally from the implementation of the assurance requirements in 40 CFR 191.14.

4.1.3 Assessment of Environmental Risks

The EPA has established health-based levels for some hazardous constituents. The EPA guidance document on no-migration petitioning (EPA, 1992) provides guidance for identifying health-based levels for hazardous constituents for which EPA-approved levels have not yet been established. In the absence of established levels, this guidance will provide the framework for the identification of the appropriate health-based levels to be applied to the WIPP.

The guidance document states that lower levels will be required if needed to protect the environment. Examples of cases where lower levels may be appropriate include the potential to impact sensitive environments or endangered species. The assessment of environmental impacts is required "to determine if human health-based levels measured at the unit boundary are sufficient to protect any sensitive environmental receptors." An assessment of environmental risks will be performed and documented in the no-migration determination petition to evaluate the appropriateness of established and proposed health-based levels.

4.2 COMPLIANCE APPROACH FOR THE SHORT-TERM PERFORMANCE REQUIREMENTS OF 40 CFR 268.6

The objective of this portion of the 40 CFR 268.6 compliance program is to evaluate whether the WIPP facility will satisfy the no-migration standard in the short term. This will be done by assessing the transport of hazardous chemical constituents through the underground ventilation air stream during the disposal and decommissioning phases and by demonstrating that no other pathways are likely. In addition, monitoring and environmental risk assessment activities will be performed to meet the

requirements of 40 CFR 268.6. This process is represented by the "Compliance Approach" column on Figure 2-3.

4.2.1 Compliance Assessment

The short-term compliance with 40 CFR 268.6 will be assessed by evaluating the quantities and concentrations of hazardous constituents available for release to the underground air flow and the resulting concentrations of hazardous constituents at the unit boundary in the exhaust shaft.

This analysis will consist of the following general elements:

Evaluation of potential emissions of hazardous constituents;

Evaluation of the efficacy of natural and engineered barriers in retarding the migration of hazardous constituents through the underground air stream;

Calculation of concentrations of potentially released airborne hazardous constituents in the exhaust shaft; and

Comparison of calculated concentrations with established EPA-approved health-based levels.

It is expected that the same health-based levels that were applied to the test phase no-migration determination will be applied to this analysis. In addition, the results of this work will be the subject of sensitivity analysis and uncertainty analysis regarding the occurrence of events that may disrupt operations.

Routine operations during the disposal phase will include the simultaneous construction of one waste-emplacement panel, the emplacement of waste and backfill in a second panel, and the sealing of a third panel. The sealing of a panel will create a barrier to the movement of gas, limiting the migration of airborne volatile organic compounds through the underground ventilation air flow.

Since the sealing system will be important in limiting the migration of airborne hazardous constituents, it is necessary to demonstrate the effectiveness of the system. Knowledge of volatile constituents emanating from the wastes and knowledge of waste degradation processes occurring in the waste-emplacement rooms will be used in demonstrating the effectiveness of the sealing system.

Waste characterization data will be useful in providing information on concentrations of volatile organic compounds in the headspaces of waste containers which will support the assessment of airborne emissions of hazardous constituents during and after waste emplacement. Headspace information from waste containers will provide a basis for approximating the characteristics of atmospheres in sealed waste-emplacement rooms.

4.2.1.1 Interfaces with Research, Development, and Design Activities

Similar to the process described in Section 3.1.1.8, an interface function provides feedback to the performance assessment for the short-term 40 CFR 268.6 compliance analyses. This interface links the research, development, and design activities to the ongoing compliance assessment.

4.2.2 Monitoring Program

Short-term monitoring will focus on the air pathway. During the disposal phase, as during the test phase, air will be the pathway of concern; a demonstration that other pathways are of no consequence will be made. The design of the program will be based on experience gained through the operation of the test-phase air monitoring program. Since waste-container headspace gases will not be collected into a common manifold during the disposal phase (as they will during the test phase), air samples will likely be collected at ambient monitoring stations as opposed to source-monitoring stations. In addition, container-based control devices, such as sorptive carbon filters integrated with radioactive particulate filters, may be used if VOC concentrations prove to be higher than expected or if compliance with the no-migration standard cannot otherwise be demonstrated with reasonable certainty. Operationally, it may be useful to close disposal rooms promptly after they are filled; once closed, they will no longer contribute to the inventory of airborne hazardous constituents.

4.2.3 Assessment of Environmental Risks

Similar to the process described in Section 4.1.3 in regard to the long-term assessment of compliance, an assessment of environmental risks during the short term will be performed. This work will be aimed at evaluating the appropriateness of established and proposed health-based levels. The assessment of any sensitive environmental receptors will be key to this work.

4.3 COMPLIANCE APPROACH FOR 40 CFR 264, SUBPART X

The objective of the 40 CFR 264, Subpart X compliance program is to evaluate whether the WIPP facility will satisfy the environmental performance standard. In addition, necessary plans and procedures will be developed for compliance with all relevant Subpart X requirements pertaining to monitoring, inspections, response, reporting, corrective actions, and postclosure care. This work is represented by the items included in the "Compliance Approach" column in Figure 2-4.

The DOE will ensure that all operating conditions, limitations, and requirements specified in the WIPP facility RCRA permit are met, once a permit is issued by the State of New Mexico. To obtain a RCRA operating permit, the DOE must demonstrate that the WIPP facility will be operated in compliance with 40 CFR Part 264, including the environmental performance standard of Subpart X.

Compliance with the Subpart X environmental performance standard during the test phase of the project has been evaluated in the WIPP facility RCRA permit application. Currently, the permit application addresses the test phase of the project only. The permit application will be expanded, or a revision of the permit will be requested, if the DOE decides to proceed with the disposal phase of the project.

The current analysis of compliance with the environmental performance standard for the test phase concludes that no adverse health or environmental impacts will be associated with emissions of hazardous constituents from the WIPP facility during the test phase. This analysis is currently undergoing review by the State of New Mexico, through its evaluation of the WIPP facility RCRA permit application.

Compliance with the standard during the disposal and decommissioning phases of the project will be evaluated through analysis of the potential impacts of the facility upon human health and the environment. This analysis of risk will be performed by evaluating the quantities, concentrations, and toxicities of hazardous constituents available for release to the environment, potential pathways for release, potential receptors, and the consequences of such releases.

As described in earlier sections of this plan, during the test, disposal, and decommissioning phases of the project, airborne transport is the only pathway expected to be of concern. During the 30-year postclosure phase, no pathway for transport is expected to exist. Modeling analysis will be performed to evaluate this expectation.

Since the postclosure period of concern for RCRA waste management units is 30 years, no long-term (i.e., greater than 30 years) evaluation of compliance with the environmental performance standard is believed to be required under the 40 CFR 264, Subpart X program. The undisturbed performance of the repository during the first 30 years after decommissioning will be evaluated.

Risk analyses will be performed to evaluate human health and environmental effects of airborne releases of hazardous constituents from the WIPP. These analyses will address the effects during routine operations and will generally consist of the following:

Evaluation of emissions of hazardous constituents during routine operations;
Postulation of potential airborne releases;
Simulation of atmospheric transport using dispersion modeling techniques; and
Prediction of resulting exposures to human and environmental receptors.

The results of this work will be used to assess potential levels of risk to human and environmental receptors to assess compliance with the environmental performance standard.

In several respects, this analysis is similar to that to be developed for the demonstration of compliance with the no-migration standard in the short term. Information that is needed for both activities is related to the effectiveness of the backfilling and sealing system, knowledge of volatile hazardous constituents emanating from the wastes, knowledge of waste degradation processes occurring in the waste-emplacement rooms, and understanding of interactive waste/repository processes evolving in each waste-emplacement room. Information obtained from bin-scale and alcove-scale studies will support the 40 CFR 264, Subpart X program by developing a realistic approximation of airborne emissions from wastes.

4.4 INFORMATION NEEDED FOR COMPLIANCE

Information needed to demonstrate compliance with 40 CFR 268.6 and 40 CFR 264, Subpart X may be grouped into three categories: natural barriers, repository design and engineered barriers, and waste interactions (see Figures 2-2, 2-3, and 2-4). These information needs, and the activities planned to satisfy these information needs, are described in the following sections.

4.4.1 Natural Barriers

Natural barriers are features of the site that contribute to the isolation of the TRU mixed waste. A no-migration variance petition addressing the disposal, decommissioning, and postclosure phases of the WIPP Project must include a comprehensive characterization of the disposal unit site, including an analysis of background air, soil, and water quality (40 CFR 268.6(a)(3)).

A thorough discussion of the facility's natural environment is required, since the natural setting is crucial to the demonstration of no-migration. Sufficient detail will be presented to allow an assessment of the degree of waste isolation achievable. Moreover, background water, soil, and air quality will be characterized to facilitate an adequate evaluation of the impacts of the disposal of untreated waste.

Geologic descriptions will discuss both regional and local geology, including structure, subsurface geology, geomorphology, geologic stability, soils, and topography. Site-specific information will be provided to the extent possible.

A comprehensive description of regional, local, and site-specific ground-water features will be included in the petition. Data requirements that will be addressed include identification of all aquifers and confining layers; characteristics including thickness, porosity, permeability, hydraulic conductivity, and storage; approximate ground-water elevations and seasonal variations; approximate aquifer interconnections; flow rates, directions, and recharge/discharge areas; and locations of all wells that withdraw ground water from the vicinity of the facility. Of particular interest at the WIPP facility is characterization of the Salado Formation, the host rock for the repository and the principal natural barrier to the transport of contaminants.

Surface-water information, just as ground-water information, will include the regional, local and site features that influence surface-water movement. Of particular interest are flood plain maps and facility features that control run-off and run-on.

Meteorological and climatological information will be provided to support the evaluation of the impacts of these factors on waste constituents migration. Since the DOE uses meteorological information in modeling off-site releases from the WIPP facility, a significant amount of site-specific meteorological information is available.

Finally, as part of the site description, a description of background environmental quality is required. This description includes air, soil and water quality and any other factors that are appropriate for the particular setting. Environmental characteristics of the WIPP site have been thoroughly documented in an extensive collection of scientific and regulatory-compliance documents published over a period of many years. Much of this information has been incorporated, either directly or by reference, into the WIPP final (DOE, 1980a), and supplemental (DOE, 1990b) environmental impact statements, and the *Final Safety Analysis Report* (DOE, 1990a).

Although the characteristics of the WIPP site are well documented (DOE, 1980a; DOE, 1990a; DOE, 1990b), there are several areas where the EPA has indicated that more information is expected before a disposal decision can be made. These areas were identified in the background information document for the test phase no-migration determination and are based on statements by the DOE regarding data collection programs that were either underway or were planned. These include such areas as Salado hydrologic properties with emphasis on the transmissivities of the marker beds, the far-field and near-field salt permeabilities, and the rates of brine inflow into the excavations; Non-Salado hydrologic properties, with emphasis on regional hydrology and ground-water flow patterns; and regional geochemistry relative to dissolution studies.

The DOE's approach is to draw to the extent pertinent and applicable upon studies being conducted to support the 40 CFR Part 191 program. Specifically, information will be taken from the following activities: Salado Hydrologic Properties, Salado Transport, and Site Characteristics. These activities are the same as those applicable to the disposal regulations; they are described in Section 3.2.1.

4.4.2 Repository Design and Engineered Barriers

Information pertaining to the repository design and engineered barriers must be included in the no-migration variance petition (40 CFR 268.6(a)(1)). The RCRA permit application, which must demonstrate compliance with the 40 CFR 264, Subpart X environmental performance standard, must also provide this type of information.

For a no-migration variance petition, the EPA requires that the owner/operator provide enough detail to acquaint the reviewer with the facility, its operation, and the engineered barriers important to the isolation of waste. Pertinent information includes location; points of contact; the nature of the businesses served by the facility (that is, the generators of the waste); and detailed design, layout and operating plans. In the case of the WIPP facility, the level of detail provided in the RCRA permit application is believed to be appropriate for the petition.

Most of the information needed to complete the facility description is available. Some exceptions, however, are noted in the background information document for the test phase no-migration determination. These are associated with the development of seals and plugs, the determination of the role of the disturbed rock zone, the refinement of the geomechanical model, and operations associated with waste retrieval and underground maintenance.

The DOE will draw upon ongoing activities to enhance knowledge in these areas. Specifically, information will be taken from the following activities: Disposal Room Performance; Shaft, Drift, and Borehole Seals Performance; Shaft, Drift, and Borehole Seals Designs; Disturbed Rock Zone Permeability; and Shaft, Drift, and Borehole Closure. These activities, which are the same as those applicable to the disposal regulations, are described in Section 3.2.2.

4.4.3 Waste Interactions

Additional data describing the character of the TRU mixed wastes to be emplaced in the WIPP facility are needed to support the no-migration variance petition and the RCRA permitting process. In its no-migration determination for the test phase (EPA, 1990a), the EPA indicates that the following information is needed:

> Waste characterization data to support a demonstration that TRU mixed wastes are sufficiently similar to allow the results of test phase experiments to be extrapolated to the TRU mixed wastes that DOE wishes to emplace in the WIPP during the disposal phase (EPA, 1990a); and
>
> Waste characterization data to provide the source term used in computer modeling simulating the potential for the migration of hazardous constituents from the repository in the long term.

In addition, the following waste characterization information is required to be included in the no-migration variance petition for the WIPP disposal, decommissioning and postclosure phases:

- An identification of the specific waste . . . for which the demonstration will be made (40 CFR 268.6(a)(1)).
- A waste analysis to describe fully the chemical and physical characteristics of the subject waste (40 CFR 268.6(a)(2)).

As required by the regulation, the no-migration demonstration must meet the following criteria:

- All waste and environmental sampling, test, and analysis data must be accurate and reproducible to the extent that state-of-the-art techniques allow (40 CFR 268.6(b)(1)).
- All sampling, testing, and estimation techniques for chemical and physical properties of the waste and all environmental parameters must have been approved by the Administrator (40 CFR 268.6(b)(2)).

The Waste Interactions activity includes studies planned to satisfy these requirements. The activity will focus on characterizing the source term, including understanding waste interactions and reactions, gas generation, and degradation processes and products.

The DOE will draw upon studies being conducted to enhance knowledge of the source term. Specifically, information will be taken from the Gas Generation Characteristics activity, which is described in Section 3.2.3 of this Plan. Additional related activities will be pursued. These include: Waste Characterization (Section 4.4.3.1) and RCRA Constituents Source Term in Disposal Room Brine and Gas (Section 4.4.3.2).

4.4.3.1 Waste Characterization Activity

Objectives

The hazardous chemicals to be emplaced in the WIPP facility will be characterized in accordance with established waste-characterization plans to allow the prediction of the potential for migration of these constituents. This information will be used in RCRA compliance models to define the quantity and fate of hazardous constituents potentially available for transport from the repository. Questions associated with the nature of the waste will be addressed through this work: What is the hazardous materials inventory that should be used as a source term in the no-migration variance petition and in the RCRA permit modification? What hazardous constituents are predominant in the waste? How accurate are DOE's estimates of the chemical composition of the waste?

The characteristics of the hazardous wastes to be emplaced in the WIPP facility have been defined through knowledge of the materials and processes associated with the generation of the waste and through some sampling and analysis programs. The DOE has developed the *Waste Characterization Program Plan* (DOE, 1992c) to define waste characterization activities that will be performed to verify the current waste descriptions. The WCPP (DOE, 1992c) addresses characterization activities to be performed in support of both the RCRA and the 40 CFR Part 191 compliance programs. In addition, the *Waste Analysis Plan* (WAP) included in the WIPP RCRA permit application (DOE, 1993b) specifically addresses RCRA waste characterization requirements for the test phase, including the need to define the composition and quantity of hazardous constituents present in the waste.

In the near term, it is important that any data needed to support the no-migration variance petition are generated during the test phase and that these data are documented to be of sufficient quality. Avoiding delays in the program at the end of the test phase will require that TRU mixed wastes located at all DOE generation and storage sites be characterized during the test phase.

Also, waste characterization data to be developed in response to conditions of the no-migration determination for the test phase will be used to support the long-term petition. These data will provide information on concentrations of VOCs in headspaces of waste containers which will support the assessment of expected airborne emissions of hazardous constituents during the disposal and decommissioning phases. These data and data characterizing semi-volatile organic compounds and metals will help to define the chemical constituents source term to be used in modeling the migration of hazardous constituents.

The planned TRU mixed waste characterization activities can be broadly classified into the following areas:

Characterization during the test phase in preparation for a decision to proceed with the permanent disposal of waste. The characterization of wastes at all of the DOE sites planning to send waste

to the WIPP facility will be required for evaluating whether the repository may be operated in compliance with the applicable regulations.

Characterization during the disposal phase to document compliance with all applicable WIPP regulatory requirements as the waste is generated, retrieved, and shipped after the test phase.

The overall waste characterization program to support the test phase is defined in the WCPP (DOE, 1992c). The focus of the plan is to provide the DOE sites with information needed to initiate and implement the characterization program. The components of the program are described in Table 4-1.

The EPA has specified that a no-migration determination can only be issued for the specific wastes described in the petition. Furthermore, the wastes must be shown to be compatible with each other and with the facility. The EPA and the State of New Mexico specifically require information on the waste types and the sources of the waste, including applicable hazardous waste codes, generating process descriptions, waste quantities, and other properties that influence the potential for the waste to migrate or to pose a threat to human health or the environment.

In addition, for the disposal phase, the DOE must demonstrate that the TRU mixed waste proposed for disposal is represented by the waste used during testing, in terms of the gas-generation potential of the waste (EPA, 1990a). The DOE plans to apply an "envelope" or "bounding" approach in which TRU mixed wastes whose characterization (for gas generation potential) is within that envelope would be considered "representative" of the test phase wastes. Only those wastes falling within the bounding envelope could be emplaced in the WIPP. The envelope concept does not release a waste generator of his responsibility to perform waste characterization.

Initially, TRU mixed wastes will be characterized at the Idaho National Engineering Laboratory and the Rocky Flats Plant during the loading of test bins. Prior to the end of the test phase, however, TRU mixed waste characterization information from other generator sites will be needed to support the development of the source term for the long-term no-migration determination petition and the revised RCRA permit application. Specific questions to be answered are associated with verifying the process knowledge that has been documented by the generators of the TRU mixed waste. This activity includes implementing a sampling and analysis program aimed at identifying the hazardous constituents and their concentrations and distributions.

Potential waste transformations, reactions, and degradation products will be evaluated as part of defining the source term. The no-migration variance petition and the RCRA permit application must evaluate potential waste transformation mechanisms that alter waste toxicity or mobility. The potentials for the formation of leachate and for the volatilization of organics such that transport is possible are also of interest. The EPA recommends evaluating the following mechanisms of waste transformation: biodegradation, hydrolysis, oxidation/reduction, and volatilization. For radioactive mixed waste, potential radiolytic transformations will also be assessed.

Waste transformation information may be useful in the waste constituents release and transport modeling for demonstrating decay with time in the concentrations and toxicities of hazardous constituents. Biodegradation and half-lives of organic chemicals have been evaluated and are documented in the open literature. The applicability of existing data, their acceptability to the EPA and the State of New Mexico, and their benefit to the waste release and transport modeling will be evaluated. The DOE's approach will be to use documented information to the extent possible. If insufficient information exists, or if the quality and the type of published data are inadequate or inappropriate to satisfy relevant quality standards, laboratory experiments will be designed and implemented to verify results or to provide new data.

Table 4-1. Components of the TRU Mixed Waste Characterization Program

Purpose of Characterization	Sites Responsible for Characterization	Time Period for Characterization	Applicable Requirements[1]
Characterization for the WIPP experimental program	Sites providing the waste for the experimental program (bin and alcove programs)	Test phase	A,B,C,D,E
Additional characterization during the test phase in support of WIPP disposal decision[2]	All sites	Test phase	A,B,C,D
Characterization during the disposal phase to show ongoing compliance with governing regulations[2]	All sites	Disposal phase	A,B,D,F,G

[1]The following are the applicable requirements:

A = WIPP operations and safety criteria
B = Transportation requirements
C = Requirements of the no-migration determination
D = Requirements of the Waste Analysis Plan in Part B of the RCRA permit application (DOE, 1993b)
E = Requirements of the experimental program specified by Sandia National Laboratories
F = Future requirements of a no-migration determination for the disposal, decommissioning, and postclosure phases
G = Future requirements of the performance-assessment program (these will replace requirements of the experimental program)

[2]Requirements are not fully defined for the disposal phase.

Waste compatibilities will be assessed to avoid the mixing of incompatible wastes that may react to form hazardous gases, that may cause violent explosive reactions or excessive heat, or which may enhance the solubilization and mobilization of hazardous constituents. The compatibility assessment will include all components of the waste disposal system. The compatibility of the seal materials and the backfill materials with the hazardous constituents will also be evaluated. This evaluation will be made using EPA guidance, once materials are selected.

Reactions that would be of concern would be those that create excessive heat, fire, or explosion; rapid degradation of containers or seals materials; or complexation processes that may enhance the solubilities of hazardous compounds. Additional reactions of interest are chemical, microbial, and possibly radiolytic degradation of hazardous organics into non-hazardous compounds. In some cases, hazardous compounds may be converted into other compounds that are themselves hazardous. Scientific question that must be resolved in this regard include: Are wastes compatible with one another? Are wastes compatible with their containers? Are wastes compatible with materials within the repository environment? At what rates will hazardous organics degrade within the repository environment? Are hazardous degradation products generated?

An analysis of the compatibility of the wastes planned to be emplaced in the WIPP, waste containers, and the salt formation has been performed and included in the WIPP facility RCRA permit application. The analysis demonstrates that no adverse reactions posing a safety or waste-isolation threat will occur. Literature surveys (and laboratory experiments, if necessary) will be performed to identify degradation rates for hazardous organic compounds in the repository and flow path environments. These degradation rates will be used where appropriate to calculate the inventories of hazardous constituents as a function of time both in the repository and along flow paths in a manner analogous to the decay of radionuclides. Potential transformations of hazardous organic compounds to other hazardous organic compounds will also be considered.

Relevance to Compliance

Characterization of waste is necessary to define the hazardous constituents source term. Analysis of the compatibilities of materials is necessary to ensure safety and is required by RCRA regulations (40 CFR 264.17). Consideration of organic degradation processes will provide realistic inventories of organic compounds as a function of time and facilitate understanding of the expected geochemical interactions that influence the release of hazardous constituents from the source. Use of parameter values available through the literature will prove cost-effective, to the extent that this approach is deemed appropriate. Confirmational testing may be required to reduce uncertainties if necessary.

4.4.3.2 RCRA Constituents Source Term in Disposal-Room Brine and Gas Activity

Objectives

The objective of this activity is to understand the composition and behavior of hazardous constituents in the WIPP waste-emplacement rooms. Understanding of the emission of gases from waste containers, including gas generation rates, is also a part of this work. This activity is designed to provide confirmatory information in regard to gas generation modeling and will help to define the source term used in modeling evaluations of the behavior of the repository

Hazardous waste constituents in the WIPP inventory can be placed into two broad groups: organics, (including volatile and semi-volatile hydrocarbons) and inorganics such as metals. The dominant mechanism for the release and transport of metals is dissolution in brine and transport either along anhydrite beds within the Salado Formation or along drifts and shafts. Migration by liquid-phase

transport will be limited by the volume of brine available for transport and the solubilities of hazardous constituents in that brine. These solubilities may be needed if models project that fluids will migrate to the unit boundary or if conservative assumptions cannot be used.

Gas-phase transport from the closed repository will be limited by the number of moles available for transport and equilibrium vapor pressures of each organic constituent in the gas mixture at the anticipated temperature and pressure in the repository environment. These equilibrium vapor pressures will be determined if conservative assumptions are deemed to be inappropriate. This information will set upper bounds on the masses of hazardous constituents that can be transported by a unit volume of contaminated brine or gas.

The solubilities of metals in brine, if needed, will be predicted using geochemical modeling techniques combined with appropriate thermodynamic data. Calculations of this type are fairly accurate in dilute water but are more uncertain as the ionic strength of a liquid, such as brine, increases. The potential for the formation and transport of colloidal hazardous constituents will also be evaluated. For calculations involving saturated brine, for which supporting data are available, this technique can be used to set upper bounds on solubility limits as a first approximation. If compliance can be demonstrated using these upper bounds, then only confirmatory laboratory experiments will be necessary. For cases for which data are unavailable and where conservative assumptions are not adequate, experiments will be necessary.

Hazardous organic compounds will tend to distribute themselves between liquid and gas phases. The degree of distribution is a function of several parameters including total pressure, solubility in the liquid phase and equilibrium vapor pressure in the gas phase. Solubilities in pure water of the organic compounds of interest to the WIPP facility are established. These solubilities tend to decrease in higher-ionic-strength solutions such as saturated brines. Equilibrium vapor pressures of volatile organics will be calculated in complex gas-phase mixtures from existing mixing models and thermodynamic data. Confirmatory testing for the complex two-phase mixture may be required if data are not available and if conservative assumptions are unacceptable.

In addition to determination of the VOC source term through waste characterization efforts at the waste generator/storage sites, studies with bins and alcoves will be performed to gather data in simulated and actual repository environments. These tests will be indexed to the operational time span of phased-closure seal emplacement (see Section 4.2.1). The bin tests will simulate environments of as-received "dry" waste through brine-inundated environments, while the alcove test(s) environment will be "dry" going to humid (relative humidity of approximately 70 percent) after the alcove seal has been emplaced and closed. Tests with materials that simulate waste may be initiated soon and generate data for a longer time. In addition, data from TRU mixed waste bins configured to the dry and humid waste environments will confirm results of tests with simulated wastes and factor in radiolysis (which is initially more dominant) in the assessment of synergism of gas generation processes and any alteration of known VOC source terms.

The waste characterization and source term programs will gather data regarding the gases that are present inside drums, but will not provide information regarding the effectiveness of drum seals in retarding the release of gases from the drums. Containers currently being used to store the TRU mixed waste at the DOE waste generation and storage sites are closed with a lid and closure ring or band. Some of the drums also have a closure gasket between the drum and lid that is designed to be permeable to gases. Additionally, some of the drum lids are fitted with carbon-composite filters (the effectiveness of filters in limiting emissions of VOCs from waste containers is being evaluated by laboratory studies). The effectiveness of a drum in containing gases is a function of the effectiveness of the lid seal, gasket effectiveness, and filter effectiveness in appropriate combination. The primary

reason for the alcove test is to allow the DOE to measure in a macroscopic manner (1,050 drums) the overall emissions of gases from an array of drums having the various sealing and gas filtration configurations.

Prior to the initiation of the alcove tests, both an alcove gas-barrier system and a gas management/sampling system will be designed, fabricated, and tested. A trade-off study, preliminary design, and final design (with construction specifications) have been completed and thoroughly reviewed for the alcove gas-barrier system. Construction and testing of the gas barrier are needed to validate this concept. Design of the gas management system can be initiated after specific requirements are established for this system.

Relevance to Compliance

Solubility limits for hazardous constituents in brine and gas are required as input to RCRA-compliance models. This information will set upper bounds on the quantities of hazardous constituents that can be transported by unit volumes of contaminated brine and gas. Use of parameter values available through the literature will prove cost-effective, to the extent that this approach is deemed pertinent and appropriate. Confirmational testing may be required if necessary to reduce uncertainties.

The results of the bin-scale and alcove-scale studies will provide confirmatory data for modeling estimates of the quantities and chemical compositions of gases in waste emplacement rooms. They will provide information relevant to the rate of release of VOCs into disposal rooms and the rate at which disposal rooms may become pressurized. This information will provide better understanding of the mechanisms tending to drive gases out of the disposal rooms and through the disturbed rock zone and panel seals.

Chapter 5

Studies Supporting the Test Phase Activities

5. STUDIES SUPPORTING THE TEST PHASE ACTIVITIES

This chapter contains descriptions and justifications of studies that are currently in progress or will be undertaken soon to provide information to support the regulatory compliance assessments for the WIPP. Extensive investigations (primarily site characterization and repository design) and analyses have been completed. In general, completed work is not described and status of ongoing work is described only as appropriate for defining work yet to be done. Readers who wish to become familiar with previous work, its status, and the context of its incorporation into analyses and assessments are referred to the FSEIS (DOE, 1990b), NMVP (DOE, 1989), and the three completed preliminary performance assessments (Bertram-Howery, et.al., 1990; SNL, 1991; and SNL, 1992).

5.1 Natural Barriers

The natural barriers of the WIPP disposal system comprise two groups: (1) the Salado Formation, which is the host rock for the planned repository, and (2) the rock units that overlay the host rock for the planned repository, called the non-Salado group. Both groups of barriers play an important role in the performance of the WIPP disposal system: preventing or inhibiting the release to the accessible environment of radionuclides and hazardous chemical constituents from the waste. To date, the scenarios that have been developed to predict long-term performance have indicated that one unit—a dolomite layer known as the Culebra Dolomite Member of the Rustler Formation—could provide a pathway to the accessible environment, especially in the event of inadvertent human intrusion (i.e., drilling in search of petroleum resources) into the repository (see Figure 1-3).

Three sets of activities are supported by the studies described in this section. The first set of activities are designed to provide information and understanding to evaluate the ability of the Culebra and surrounding units to adequately confine the waste disposed of in the repository after inadvertent human intrusion. These include the Non-Salado Hydrologic Properties (Section 5.1.1) and Non-Salado Transport (Section 5.1.2) activities. The objective of the studies that comprise the Non-Salado Hydrologic Properties Activity is to provide an understanding, in the form of data and computational models, of the regional and local hydrogeologic flow conditions. These flow conditions may, in turn, provide for the transport of waste constituents toward the accessible environment, in the event of human intrusion. The objective of the studies that comprise the Non-Salado Properties Activity is to characterize, understand, and model the radioactive and chemical waste constituents and their potential transport toward the accessible environment.

The second set of activities will investigate the hydrologic and transport properties of the Salado Formation. These activities are Salado Hydrologic Properties (Section 5.1.3) and Salado Transport (Section 5.1.4). The objectives of the studies that comprise the Salado Hydrologic Properties Activity are to characterize, understand, and model the potential brine flow mechanisms and pathways (e.g., fractured marker beds) within the Salado Formation. The objectives of the studies that comprise the Salado Transport Activity are to characterize, understand, and model the potential transport of radioactive and chemical constituents of the waste from the repository to the accessible environment through the flowpaths in the Salado Formation.

Studies that yielded information about the site and that were performed prior to the test phase, comprise the third activity, Site Characteristics (Section 3.2.1.5). Any subsequent work that may be required to publish or further interpret data collected through these studies will be included in the Salado and Non-Salado activity sets; there are no studies to be described under a Site Characterization Activity heading.

Each of the ongoing activities is supported by several studies that are listed in Table 5-1. Studies are further categorized as a laboratory test (L), field test (F), design task (D), modeling study (M), or protocol function (P). Test plans are prepared for laboratory tests and field tests; these are also listed in Table 5-1. Individual plans are typically prepared for all tests with waste and for major non-waste field tests. Generic plans are prepared for laboratory and field studies that do not warrant individual test plans. Test plans may be revised or supplemented as tests evolve.

5.1.1 Non-Salado Hydrologic Properties Activity

The Culebra Dolomite Member of the Rustler Formation (see Figure 1-3) is the most transmissive rock layer above the planned WIPP repository. Information obtained as part of the Site Characterization indicates that the Culebra is continuous across the disposal system and is saturated with slow-moving saline ground water. The Culebra could provide a pathway for radionuclides to be released to the accessible environment if a future borehole breaches the repository. According to this scenario, radionuclides could be transported up the borehole, into the Culebra, and carried by moving ground water to an off-site stock well. Predicting possible pathways and travel times for radionuclides in the Culebra to reach the accessible environment is one of the critical tasks of the performance assessment. These pathways and travel times strongly depend on the rates and directions of ground-water flow in the Culebra and other rock units above the Salado Formation over the time periods of regulatory concern.

Uncertainties in long-term predictions of ground-water flow continue to exist for the WIPP site. Currently, two-dimensional flow models (confined aquifer models) are used to evaluate data from pumping tests and calibrate transmissivity distributions. These models make the critical assumptions that ground-water flow is in equilibrium with boundary conditions and that vertical flow between the Culebra dolomite and other units in the Rustler Formation can be neglected. These assumptions are probably appropriate for the relatively short durations of pumping tests. However, predictions of long-term paths and travel times for radionuclides derived from the confined aquifer models are considered to be tentative because these assumptions may not be appropriate for periods of thousands of years. The appropriateness of these assumptions is considered to be an important source of uncertainty, referred to as conceptual model uncertainty, in the performance-assessment process. Other reasons current predictions must be considered to be tentative are (a) data from several pumping tests have not been fully analyzed and reported, (b) the effect of climate change on the confined-aquifer model boundary conditions has not yet been determined, (c) the confined-aquifer model might not be consistent with geologic, geochemical, and isotopic information, (d) current scenarios in which gas enters the Culebra from the breach borehole have not been fully examined for the effect of the gas on Culebra flow, and (e) uncertainty resulting from spatial heterogeneity in flow properties and from related scale-up of test data has not yet been fully assessed.

To improve predictions of ground-water flow over the next 10,000 years, the following questions must be addressed. Is the ground-water system in the WIPP region in steady state or is it draining from an earlier pluvial period? Will rates of ground-water flow change in the future? How would potential climatic changes affect the path and time of radionuclide travel to the accessible environment? What effects do vertical leakage and variations in the density of ground water have, and can they be neglected? Do existing petroleum boreholes that are outside the WIPP controlled-area boundary and penetrate the low permeability units in the Rustler Formation affect ground-water flow? Are the current conceptual models of the WIPP ground-water flow consistent with all the existing site characterization data, especially the geochemical data? How would gas flowing into the Culebra affect the flow patterns? Do existing data preclude severe spatial heterogeneity in flow properties, or hidden features? What is the uncertainty in flow predictions from severe heterogeneity

Table 5-1. Natural Barriers Activities, Supporting Studies, and Associated Test Plans

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.1.1	Non-Salado Hydrologic Properties Activity		
5.1.1.1	Core Studies of Non-Salado Rock Properties	L	Test Plan: Laboratory Tests in Support of WIPP Hydrologic and Transport Studies (In preparation).
5.1.1.2	Regional-Scale Transport and Sensitivity Studies		
5.1.1.3	Model Development for the Non-Salado	M	NA
5.1.1.4	Field Testing and Data Interpretation for Non-Salado Hydrology	M	NA
		F	Experimental Plan for Tracer Testing in the Culebra Dolomite at the WIPP Site, R. L. Beauheim and P. B. Davies, 1992.
5.1.1.5	Regional Geochemical Studies	L	See 5.1.1.1
5.1.1.6	Data Base for Non-Salado Field Studies	P	NA
5.1.1.7	Validation and International Collaboration for Non-Salado Model	M	NA
5.1.1.8	Verification of Non-Salado Performance-Assessment Model	M	NA
5.1.1.9	Identifying Potential Underground Sources of Drinking Water	M/F	This study is currently a review/modeling/analysis effort. If a field test or demonstration is determined to be necessary, an appropriate Test Plan or Field Operations Plan will be prepared.
5.1.2	Non-Salado Transport Activity		
5.1.2.1	Adsorption Studies for the Non-Salado	L	See 5.1.1.1
5.1.2.2	Radionuclide Solubility and Speciation for the Non-Salado	L	See 5.1.1.1
5.1.2.3	Brine Mixing and Radionuclide Coprecipitation for the Non-Salado	L	See 5.1.1.1
5.1.2.4	Empirical Sorption Studies for the Non-Salado	L	See 5.1.1.1
5.1.2.5	Column Experiments for the Non-Salado	L	See 5.1.1.1
5.1.2.6	Long-Core Tracer Tests for the Non-Salado	L	Preliminary Test Plan: Two-Phase Flow Laboratory Program for the Waste Isolation Pilot Plant, S. Howarth, 1992 (In preparation).
5.1.2.7	Colloid Characterization and Transport for the Non-Salado	L	See 5.1.1.1
5.1.2.8	Test Design and Interpretation for the Non-Salado	M	NA
5.1.2.9	Non-Salado Data Base for Performance Assessment	P	NA
5.1.2.10	Sorbing/Retarding Tracer Tests for the Non-Salado	F	See 5.1.1.4
5.1.2.11	Data Base for Non-Salado Laboratory Studies	P	NA
5.1.2.12	Non-Sorbing Tracer Tests for the Non-Salado	F	See 5.1.1.4

Table 5-1. Natural Barriers Activities, Supporting Studies, and Associated Test Plans (Continued)

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.1.3	Salado Hydrologic Properties Activity		
5.1.3.1	Salado Threshold Pressure	L	See 5.1.1.1
5.1.3.2	Salado Relative Permeability	L	See 5.1.1.1
5.1.3.3	Salado Permeability Versus Stress	L	Test Plan: WIPP Horizon Gas Flow/Permeability Measurements, J. C. Stormont, 1988. Test Plan: WIPP Horizon In Situ Permeability Measurements, W. W. Peterson and J. C. Stormont, 1984. WIPP Horizon Permeability Measurements. [Appendix to Test Plan: WIPP Horizon In Situ Permeability Measurements, E. W. Peterson and J. C. Stormont, 1984.] J.C. Stormont 1986.
5.1.3.4	Salado Porosity	L	See 5.1.1.1
5.1.3.5	Salado Brine Chemistry	L	See 5.1.1.1
5.1.3.6	Data Base for Salado Laboratory Studies	P	NA
5.1.3.7	Repository-Scale Multiphase Modeling and Sensitivity Studies	M	NA
5.1.3.8	Model Development for the Salado	M	NA
5.1.3.9	Test Design and Interpretation for the Salado	M	NA
5.1.3.10	Validation and International Collaboration for Salado Model	M	NA
5.1.3.11	Salado Data Base for Performance Assessment	P	NA
5.1.3.12	Salado Far-Field Permeability Testing	F	Field Operations Plan for Permeability Testing in the WIPP-Site Underground Facility, G. J. Saulnier, Jr., 1988.
5.1.3.13	Small-Scale/Intermediate-Scale Brine-Inflow Experiments	F	Test Plan: Small-Scale/Intermediate-Scale Brine Inflow Experiments (In Preparation).
5.1.3.14	Large-Scale Brine-Inflow Experiments	F	Test Plan: Brine Inflow and Related Tests in the Brine Inflow Room (Room Q) of the Waste Isolation Pilot Plant (WIPP), E. J. Nowak, 1990.
5.1.3.15	Threshold-Pressure Testing of Marker Bed 139	F	Test Plan: Gas-Threshold-Pressure Testing of the Salado Formation in the WIPP Underground Facility, G. J. Saulnier, Jr., 1992.
5.1.3.16	Data Base for Salado Field Studies	P	NA
5.1.3.17	Benchmarking of Mechanistic and Performance-Assessment Models	M	NA

Table 5-1. Natural Barriers Activities, Supporting Studies, and Associated Test Plans (Concluded)

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.1.4	Salado Transport Activity		
5.1.4.1	Gas Solubility in Salado Brines	L	See 5.1.1.5
5.1.4.2	Retardation in the Salado	L	See 5.1.1.5
5.1.4.3	Tracer and Transport Testing in the Salado	F	Test Plan: Tracer Testing in Marker Bed 139 of the Salado Formation in the WIPP Underground Facility, G.J. Saulnier, Jr., and R.L. Beauheim (In preparation).
5.1.4.4	RCRA Constituents Retardation in the Salado	L	Test Plan: RCRA Constituents Retardation in the Salado Formation (To be developed).

1. D = Design Task
   F = Field Study
   L = Laboratory Study
   M = Modeling Study
   P = Protocol (data base management, integration of studies, etc.)

2. Test Plans are prepared only for laboratory and field tests
   NA: Test Plans are not applicable to Design, Modeling, and Protocol studies

or hidden features that cannot be precluded on the basis of the data? Are there potential underground sources of drinking water in the vicinity of the disposal system?

To answer the above questions, it is necessary to consider the hydrologic behavior of the Culebra near the WIPP as part of a regional hydrologic system that includes all of the rocks above the Salado and extends to the natural boundaries of the regional ground-water system. The technical approach is to build a transient three-dimensional model of ground-water flow for the WIPP region. Implementation of this approach is described by the studies in this Section 5.1.1.

5.1.1.1 Core Studies of Non-Salado Rock Properties

Description

This study will support laboratory measurements of permeability, porosity, and compressibility of core samples from the Dewey Lake Red Beds and Rustler Formations. Core samples of the Dewey Lake Red Beds, the Tamarisk Member of the Rustler, the Forty-niner Member of the Rustler, and the unnamed lower member of the Rustler will be selected from the existing WIPP core inventory and from any new holes that might be drilled during fiscal year (FY) 1993 or 1994. Measurements of permeability (horizontal and vertical), porosity, and compressibility will be made on these samples in the laboratory. The data will be used to support regional-scale flow and transport modeling (Section 5.1.1.2).

Justification

Regional-scale flow and transport modeling (Section 5.1.1.2) require the permeability and storage properties of all strata included in the model. For the more permeable units, such as the Culebra dolomite, these parameter values come from field experiments (Sections 5.1.1.4 and 5.1.1.6). For less permeable units, however, such as the claystones in the Tamarisk, the Forty-niner, and the gypsum/anhydrite layers in the Rustler Formation, field testing is impractical. Also, field testing cannot be performed in the unsaturated Dewey Lake Red Beds. For these units, laboratory tests on core samples are the only means of determining the necessary parameter values.

5.1.1.2 Regional-Scale Transport and Sensitivity Studies

Description

This study characterizes the ground-water flow in the Rustler Formation and overlying units and radionuclide transport in the Culebra Dolomite Member of the Rustler Formation over the 10,000 years of waste isolation required by the disposal regulations. The Culebra is considered a possible path for migration of contaminants from the WIPP site.

This flow modeling addresses a variety of unresolved issues associated with the nature of ground-water flow in the Rustler in general, and in particular, with the interaction of flow in the Culebra with the flow in other Rustler units. By modeling various scenarios, this study examines aspects of the natural system: the magnitude of vertical flux into the Culebra; the extent to which the geochemistry of Culebra waters reflect an evolving flow system; the possible responses of the Rustler flow system (including changes in flow rates and paths in the Culebra) to past and future changes in climate. The study also addresses possible scenarios for human interaction with the natural system including the potential impact of increased vertical flow of ground water through low permeability units due to degradation of casings in nearby oil and gas wells and the increased infiltration under surface catchment basins that could occur as the strata over future potash mines subside. This study might

also provide insight into the cause of the observed rise in water levels in Culebra wells located south of the WIPP Site.

As a result of previous work, alternative conceptual models of the Rustler flow system were identified and a preliminary three-dimensional numerical model implemented. The remaining work may include calibrating models, performing sensitivity studies, simulating scenarios, and refining models.

The single-fracture, double-porosity transport model, with mechanistic and chemical reactions, described in Section 5.1.2, will be used to calculate the sensitivity of radionuclide transport to variations in brine compositions induced by different breach scenarios. These results will be used to develop a regional-scale model that captures all significant features of the small-scale, single-fracture model (Section 5.1.1.3). The regional-scale model will calculate retardation in the Culebra using observed water compositions and will be designed to provide effective retardation factors for performance-assessment calculations.

Justification

Previous numerical models of flow in the Culebra have treated this unit in hydrologic isolation from other Rustler units and have used constant potentials along lateral boundaries of the modeled region to drive the flow. Implicit in this model setup are the assumptions that the regional flow field is in steady state, that the flow system is much more extensive than that of the modeled region, and that vertical fluxes are insignificant. Although this approach has been useful for delineating the transmissivity distribution of the Culebra and identifying possible pathways of contaminant release, it does not provide a basis to evaluate the unresolved issues discussed above. These issues, as well as the uncertainty in conceptual models that have been implemented in performance-assessment calculations, have been cited by NAS and consultant review committees as essential considerations for performance assessment and for demonstrating a comprehensive understanding of the hydrogeologic behavior of the site. By treating the Culebra as one component of a three-dimensional, unconfined system with boundaries that explicitly represent physical processes, this study is designed to provide an analytic framework for addressing these issues.

Current transport calculations rely on sorption models that assume constant chemical compositions along the flow path, a condition that is not met by the Culebra system. Preliminary laboratory experiments (Section 5.1.2.5) show the inadequacy of that simple model for describing actual transport behavior. The chemical retardation model developed here represents the phenomena that cause retardation, allowing effects of varying local chemical environments on transport to be determined. This study enables determination of "effective retardation factors," which can easily replace distribution coefficients in existing codes and is designed to provide a good representation of retardation in the Culebra.

The flow modeling receives support and information from studies described in Sections 5.1.1.4, 5.1.1.5, 5.1.2.12, and 5.1.2.10. It will contribute to studies described in Sections 5.1.1.3 and 5.1.1.7, and to the performance-assessment (Sections 5.1.1.8 and 5.1.2.9). The transport modeling relies on data collected from studies described in Sections 5.1.2.1, 5.1.2.2, 5.1.2.3, and will be used (Section 5.1.2.8) to help design and interpret the column experiments (Section 5.1.2.5).

5.1.1.3 Model Development for the Non-Salado

Description

This study involves developing and modifying flow and transport models for use in the regional-scale transport and sensitivity studies discussed in Section 5.1.1.2.

A single-fracture, double-porosity model with a chemical equilibrium simulator will be developed to calculate the sensitivity of radionuclide transport to variations in brine composition induced by differing breach scenarios (Section 5.1.1.2). These results will be used to develop a regional-scale model that captures all significant features of the small-scale model. The regional-scale model will calculate retardation in the Culebra using brine compositions observed in the Culebra.

The breach scenario could lead to both brine and gas flowing up the borehole into the Culebra. The gas phase might be primarily hydrogen, so a model might need to be developed that can handle both gas/aqueous flow and the alteration to reducing conditions in the aqueous flow caused by hydrogen. Also, the presence of gas leads to reduced contact between the aqueous and mineral phases; the effect of this surface contact reduction on effective retardation factors has not been assessed.

To use these flow models for regional-scale transport and sensitivity studies (Section 5.1.1.2), computational models capable of solving transient, three-dimensional flow equations will be developed. These computational models will be used to simulate two important physical aspects of the Rustler flow-system: that the density of the ground water varies, and that the water table may move in response to climatic change.

Modifications to existing models necessary to allow them to be applied for flow and transport analysis in the Rustler Formation are performed as part of this study.

Justification

To adequately predict radionuclide transport over 10,000 years, all important phenomena involved, including chemical and flow behavior, must be adequately understood. Because appropriate computer codes are not yet available, new codes will be developed and existing codes will be modified.

The flow models address unsolved issues for performance-assessment calculations, provide input to transport models, and demonstrate the understanding of Rustler hydrogeology. Development of transport models relies on data collected in conjunction with the studies described in Sections 5.1.2.1, 5.1.2.2, 5.1.2.3 and which are used in the studies described in Section 5.1.2.8 to help design and interpret the column experiments characterized in Section 5.1.2.5. Developing flow models contributes to the work set forth in Sections 5.1.1.7 and 5.1.1.8. The work delineated in Section 5.1.1.2 cannot proceed without information from this study.

5.1.1.4 Field Testing and Data Interpretation for the Non-Salado Hydrology

Description

The field hydrologic testing and interpretation study focuses on field hydrologic testing and analysis to quantify the primary physical parameters controlling ground-water flow within the Rustler Formation, particularly within the Culebra Dolomite Member. The primary parameter controlling ground-water flow in the Culebra is the transmissivity distribution, which is related to the distribution of fracturing. While extensive hydraulic testing has been carried out in the Culebra, not all tests have been fully

interpreted and reported. Given the extreme heterogeneity of the transmissivity distribution in the Culebra, final interpretation and reporting of the remaining hydraulic tests will provide important additions to the transmissivity data base used for numerical modeling.

Recent evaluation of existing tracer test data (Sections 5.1.2.8 and 5.1.1.7) suggests that an additional field-scale tracer test specifically designed to differentiate between double-porosity and channeling models of radionuclide transport is necessary. The hydraulic testing performed as part of that tracer test will add to the existing hydrologic data base for the Culebra and will be accomplished and reported under this study.

Geochemical studies (Section 5.1.2.10), Rustler flow and transport modeling studies (Sections 5.1.1.2 and 5.1.2.8), and model validation exercises (Section 5.1.1.7) may indicate a need for additional hydraulic testing of the Culebra or other Rustler members. Any such additional testing would be planned, performed, interpreted, and reported under this study.

Justification

Regional-scale hydrologic modeling (Section 5.1.1.2) and numerical performance-assessment modeling of contaminant-migration scenarios rely on both a conceptual understanding of significant processes, mechanisms, and phenomena, and a defendable quantitative data base of pertinent flow parameters. These can only be obtained through a field experimental program directed at identifying significant processes and defining and quantifying important parameters. Hydraulic testing is designed to provide necessary information on the regional distribution of fracturing and transmissivity.

5.1.1.5 Regional Geochemical Studies

Description

The regional geochemical studies combine work in three areas: analysis of the stable isotopic composition of soil water at the WIPP site, analysis of the solute content of Rustler ground waters, and radiocarbon studies of Rustler ground waters.

The analytic techniques for measuring the isotopic composition of soil waters have been refined and future sampling and measuring strategies have been evaluated. The initial data indicate that there is recharge to the unsaturated zone. Additional sampling is planned to better understand the isotopic systematics of recharge through the unsaturated zone.

Solute data collected through 1986 have been documented and evaluated. Analytical work will continue as needed, and a report to disperse the new data and evaluate all information will be completed.

Radiocarbon samples collected between 1985-1988 have been analyzed and the results have been interpreted. Samples from one or two additional locations will be collected if necessary, and a final interpretive report is planned.

Justification

Investigators have used the similarity, or lack thereof, of the stable isotopic composition of Culebra water and modern meteoric water to infer the residence times of the Culebra waters. One of the difficulties in inferring residence times is that evapotranspiration changes the isotopic composition of water in the near-surface portion of the unsaturated zone. Therefore, the isotopic composition of

water that actually reaches the saturated zone at the WIPP site is not known. Increased knowledge about the isotopic composition of modern recharge might provide more information about residence times and improve simulations of how ground-water flow patterns in the Rustler respond to climate changes.

Additional solute data are needed as input to geochemical models to determine how radionuclides might be transported in the event of a repository breach, to help formulate a model of the geochemical evolution of ground waters in the Rustler, and to interpret the radiocarbon data.

Additional radiocarbon studies of Rustler ground waters have been stipulated by the State of New Mexico as a part of the studies performed in lieu of the sorbing-tracer test. In addition, information resulting from this study might delineate the uncertainty in radiocarbon-activity measurements.

The regional geochemical studies are designed to provide support for studies described in Sections 5.1.2, 5.1.1.2 and 5.1.1.3.

5.1.1.6 Data Base for Non-Salado Field Studies

Description

This study supports compilation/summation of data from field experiments into a data base for use in performance assessment. This data base will be integrated with the laboratory studies data base (Section 5.1.2.11) to provide recommendations on non-Salado hydrologic parameters for the performance-assessment data base (Section 5.1.2.9) and international collaborative groups (Section 5.1.1.7). The data base will contain raw and processed data, references used in data reduction and analysis, documentation and recommendations for intended use, data limitations, and statistical parameter distributions.

Justification

Hydrologic and transport parameters of the water-bearing formations above and below the Salado are needed for the iterative performance assessment. This study is designed to provide input parameters and model implementation recommendations to the performance-assessment data base for incorporation in annual compliance calculations. The input parameters to be derived, determined, or inferred from this study include transmissivities, storativities, and hydraulic heads of the units of interest.

5.1.1.7 Validation and International Collaboration for Non-Salado Model

Description

This study supports the WIPP Culebra test case submitted to the INTRAVAL for Phase II and other international collaboration work. The work includes communication of data that support the test case, funding of an outside expert to evaluate the test case independently, and attending meetings to discuss WIPP data and model validation techniques and alternate validation approaches used by international teams. The WIPP Culebra test case was accepted by the INTRAVAL for Phase II in October 1990. Phase II work began in April 1991, and will last for three years. The INTRAVAL Project, or its participants, have extended their collaboration on the WIPP test case past the termination date for INTRAVAL, Phase II.

Justification

Performance-assessment mechanistic models should be validated to the extent possible. Publication and the concomitant scientific review of data and models contribute to the model validation process. Expert panels may also be needed to evaluate models and data.

INTRAVAL participation provides review of WIPP flow and transport modeling in the Rustler by international teams of experts. The teams seek to reach a consensus on the adequacy of the Culebra data base and modeling and to recommend specific additional experiments and modeling approaches to resolve remaining uncertainties. This study fosters public confidence in WIPP model validation.

This study interacts with the studies described in Sections 5.1.1.2, 5.1.1.4, and 5.1.1.6. In addition, information obtained from this study will support studies described in Section 5.1.2.8 and performance assessment.

5.1.1.8 Verification of Non-Salado Performance-Assessment Model

Description

This study supports performance-assessment calculations that involve models of ground-water flow in the Rustler and overlying units. Work includes helping to design and test codes to accommodate a variety of conceptual models of the long-term hydrogeologic behavior of the Rustler. In addition, results of three-dimensional calculations of flow in the Rustler (Section 5.1.1.2) are used to validate performance-assessment models and to identify ways to simplify the performance-assessment calculations without eliminating aspects of the hydrogeology that affect contaminant transport in the Culebra.

Justification

Performance-assessment calculations must reflect uncertainty about geologic, physical, and chemical processes that might influence the release of radionuclides from the site. To account for this uncertainty, Monte Carlo simulations of radionuclide release are developed. Each simulation requires hundreds of calculations to incorporate a representative sample of values for model parameters. Therefore, it is necessary to use simplified models to accomplish these calculations with the available computer resources. Collaboration in developing and testing computer models, and comparing results of the performance-assessment models with more detailed models will ensure that performance-assessment calculations fully represent the processes that are critical to the performance of the repository.

This study will receive support studies described in Section 5.1.1.2 and will contribute to the performance assessment.

5.1.1.9 Identifying Potential Underground Sources of Drinking Water

Description

Underground sources of drinking water are defined by the EPA in terms of the quantity and quality of ground water in aquifers. This study is designed to provide maps of estimated sustainable pumping rates and concentrations of total dissolved solids (TDS) for potential underground sources of drinking water above the Salado Formation.

Sustainable pumping rates depend primarily on the transmissivity of the aquifer and the available drawdown. Much information about these parameters has been obtained during the site characterization for the Culebra dolomite, and to a lesser extent, for the Magenta dolomite. These are the members of the Rustler Formation that are most likely to contain potential sources of drinking water. Rocks above the Rustler are not as likely to contain sources of drinking water because they are thought to be unsaturated or, where saturated, to yield ground water from permeable zones of limited lateral extent. However, existing stock wells are completed in strata above the Rustler to the south of the WIPP site. This study will be based on values of transmissivity and TDS that have been measured as part of the site characterization. Additional test holes will be drilled and pumping tests performed if required to identify and delineate potential underground sources of drinking water.

This study will document, for past and continuing hydrologic studies, the procedures for determining the TDS of ground waters from strata above the Salado Formation. If those procedures differ from those specified in 40 CFR Part 136, benchmark experiments will be performed to demonstrate how TDS values obtained by these procedures compare with values obtained by methods specified in 40 CFR Part 136. Additional water samples will be collected and analyzed if required.

Justification

The proposed rule, 40 CFR 191, Subpart C, provides for protection of underground sources of drinking water for 10,000 years of undisturbed performance. Calculations of undisturbed performance that have been performed to date indicate that radionuclides would be contained in the Salado Formation, the host rock for the repository. No portion of the Salado is a potential underground source of drinking water. This study, if required, would identify potential underground sources of drinking water above the Salado Formation in the vicinity of the WIPP disposal system.

The concentration of TDS, as defined in the proposed Subpart C to 40 CFR Part 191, must be determined according to methods specified in 40 CFR Part 136. This study will assure that methods used to determine TDS meet the requirements of 40 CFR Part 136.

5.1.2 Non-Salado Transport Activity

If radionuclides were transported up a breach borehole and into the Culebra, the transport pathway and travel time would strongly depend on the long-term ground-water flow in the Culebra and in the surrounding formations. The other major controls on radionuclide transport to the accessible environment are the retardation factors for the radionuclides traveling through the Culebra. The retardation factor for a radionuclide is the ratio of the velocity of the ground water to the velocity of that radionuclide dissolved in, or in the case of colloids, transported with the ground water.

The retardation of radionuclides can occur in the brines and rocks of the Culebra by physical retardation, without chemical reactions. The Culebra generally contains both intercrystalline and fracture porosity. The fluid flow through a rock with such a fabric is thought to be best characterized by a "double-porosity" system. In such a system, most of the ground-water flow is through the network of interconnected open fractures. The large volume of dolomite surrounding the interconnected fractures is, on average, 16 percent porous, which may provide significant storage for ground-water contaminants. Radionuclides dissolved in ground water flowing through the fractures can diffuse into the large volume of surrounding dolomite, significantly retarding the transport of the radionuclides to the accessible environment. Physical retardation can be enhanced by chemical reactions within the dolomite.

Chemical processes that lead to radionuclide retardation can occur in the absence of physical retardation. Chemical processes that lead to radionuclide retardation include adsorption onto rocks in the Culebra, ion exchange with Culebra constituents, and precipitation from ground water to a non-mobile solid. On the other hand, colloids containing radionuclides, if shown to occur, could inhibit both physical and chemical retardation.

Given the importance of retardation in the Culebra to the performance of the WIPP disposal system, the following questions must be resolved before radionuclide retardation can be proved. Is the Culebra a double-porosity system over the entire pathway or significant portions of it? If double-porosity cannot be demonstrated incontrovertibly, what other transport models must be included in the performance assessment? What are the long-term transport implications of those models? If double-porosity cannot be demonstrated incontrovertibly, how strong can the case be made to support the assumption of double porosity? What is the physical retardation in the Culebra dolomite with and without simultaneous chemical retardation? What chemical retardation processes will operate in the Culebra for each radionuclide that can reach the Culebra, with and without simultaneous physical retardation, for each brine composition and rock type encountered along the probable flow path? Can colloids exist in the brines of the Culebra? If so, how will colloid formation and transport affect retardation? What will be the effect on radionuclide retardation in the Culebra dolomite of waste-generated gas entering the Culebra from the repository via the breach borehole?

Physical retardation can be modeled independently of chemical retardation. However, only for the most simplistic chemical retardation models can chemical retardation be modeled independently of physical retardation. Validated models for each retardation mechanism will be used to predict the effect of both mechanisms operating simultaneously. The various chemical retardation mechanisms are not as easily separated, requiring a carefully planned series of single-effect and integrated-effect chemistry experiments and model development to yield radionuclide retardation data for the Culebra. The studies described in this Section (5.1.2) have as their objective the resolution of these questions.

Participants in the INTRAVAL international program have been presented the existing, strong evidence proposed for validation of double-porosity transport; namely, an integrated interpretation of all the tracer tests conducted during site characterization. In response, the INTRAVAL participants proposed a channeling model as a possible alternative conceptual model of transport in the Culebra. Such a model would have significantly different implications for long-term transport than the double-porosity model. As a result, an additional field tracer test will be conducted which will be designed to differentiate between a double-porosity transport model and a channeling transport model. International participation will be encouraged in the design and interpretation of the test.

5.1.2.1 Adsorption Studies for the Non-Salado

Description

Adsorption of radionuclides onto Culebra materials is thought to be the dominant mechanism for chemical retardation in the Culebra. An experimental matrix designed to minimize the number of experiments necessary to characterize adsorption in the highly variable ground-water and substrate compositions expected in the Culebra under different breach scenarios is being used to measure the adsorption of radionuclides as a function of water composition. This study is designed to provide values for adsorption onto corrensites, the predominant clay in the Culebra, and dolomite, the dominant rock matrix of the Culebra. These values will be used to model the scenarios important for the performance assessment. This study includes characterization of the properties of the ground water and minerals in the Culebra that could control radionuclide retardation and the development of

a thermodynamic model for the adsorption of uranium onto corrensite and dolomite. The adsorption of the uranyl (UO_2^{++}) on corrensite has been measured as part of this study.

Justification

The adsorption study will quantify adsorption of radionuclides on Culebra materials. Chemical retardation is commonly described with the distribution coefficient K_d. An evaluation of existing K_d data has demonstrated that current data on chemical retardation are inadequate to describe radionuclide transport. The information obtained from this study will be used with information from the study described in Section 5.5.2.2 to assess the total chemical barrier to radionuclide release provided by the Culebra (Section 5.4.1.1).

5.1.2.2 Radionuclide Solubility and Speciation for the Non-Salado

Description

Radionuclide solubility and speciation studies are designed to provide measurements of the dissolved concentrations of radionuclides in Culebra brines and the chemical form the radionuclides assume as a function of brine composition. Solubility in a representative suite of Culebra brine compositions will be determined for the dominant valence states of all radionuclides and hazardous constituents of interest. A data base of equilibrium constants and interaction parameters for aqueous species of uranium, plutonium, neptunium, americium, and thorium as a function of the aqueous concentrations of sodium, potassium, calcium, magnesium, chlorine, sulfate and boron solutions will then be developed.

Justification

The concentration and form of dissolved species are important for determining the retardation of radionuclides in the Culebra. This information will be used (Sections 5.1.1.3 and 5.4.1.1) to assess the chemical barrier to radionuclide release provided by the Culebra.

5.1.2.3 Brine Mixing and Radionuclide Coprecipitation for the Non-Salado

Description

This study will measure the amount of radionuclide coprecipitation that would occur should Salado or Castile brines, or both, mix with Culebra brines, in the event that brines from the repository horizon reach the Culebra as a result of inadvertent human intrusion by drilling. Precipitation of radionuclides and coprecipitation of radionuclides with nonradioactive minerals can immobilize radionuclides by incorporating them into a precipitating mineral phase. Ongoing experimental work suggests that plutonium is orders of magnitude less soluble in a Culebra water simulant than in a Salado brine simulant. Thus, precipitation of radioactive solids when contaminated brine reaches the Culebra is possible. Coprecipitation experiments will examine the potential for radionuclides to be incorporated into the crystal structure of otherwise nonradioactive minerals precipitated in the Culebra. Because contaminated brine from the repository horizon will have a substantially different composition from Culebra brine, advective and diffusive mixing near the borehole in the Culebra is likely to cause precipitation of carbonate or sulfate minerals. Incorporation of radionuclides into the mineral phase either by precipitation or by coprecipitation (Dran et al., 1988) would be a strong retardation mechanism, both through immobilization of radionuclides and reduction of the concentration of radionuclides in solution.

Justification

Confirmation of radionuclide coprecipitation with other materials, especially carbonates and sulfates, will add another significant retardation mechanism to the description of the Culebra transport system. The dynamics of mineral dissolution/precipitation in permeable media is well understood, and simulation and prediction of radionuclide retardation by precipitation can begin as soon as these data are acquired. As is the case for speciation data, these data have not been obtained because of their specialized nature, rather than difficulty in measurement. The models developed using these data will be validated against the radionuclide solubility studies described in Section 5.1.2.2. Chemical interactions between repository and Culebra fluids could cause large amounts of mineral precipitation according to predictions of validated chemical speciation codes. Such precipitation may effectively immobilize radionuclides by trapping them in the solid matrix. This study will quantify the extent of the coprecipitation of radionuclides in the Culebra. This information will be used (Sections 5.1.1.3 and 5.4.1.1) to assess the chemical barrier to radionuclide release provided by the Culebra.

5.1.2.4 Empirical Sorption Studies for the Non-Salado

Description

Batch experiments are used to examine the combined processes (adsorption, ion exchange, coprecipitation, etc.) that lead to sorption of radionuclides onto Culebra rock. Sorption of radionuclides may significantly retard the migration of these materials through the Culebra. Performing batch experiments is a practical method for measuring the sorption properties of Culebra rock.

In these experiments, crushed Culebra rock is placed in a brine solution containing the radionuclides of interest. The brine composition corresponds to that of the Culebra, and the concentrations of radionuclides are measured before and after contact with the crushed rock. The decrease in radionuclide concentrations after radionuclides contact rock is attributed to sorption. The experiments are performed over several weeks to allow enough time for sorption to occur. Because crushed rock provides additional rock surfaces, the measurements provide an upper bound on the amount of sorption that can be expected. In addition, the multiple processes of adsorption, ion exchange, and coprecipitation are not separated in batch experiments. However, these experiments are advantageous in that many different rocks and fluid compositions can be tested concurrently, yielding valuable information about the sensitivity of the combined sorption processes to the wide variety of rock types and fluid compositions present in the Culebra. These experiments complement the experiments described in Section 5.1.2.1, where considerably more effort is expected on characterization of the adsorption process, and the experiment described in Section 5.1.2.5, where the integrated flow and retardation processes are examined for typical Culebra conditions, on a limited number of water and rock compositions.

Justification

Radionuclide sorption is sensitive to the rock and fluid chemical compositions. Because the Culebra is heterogeneous, a wide variety of Culebra rock samples and brine compositions needs to be examined. The batch sorption experimental approach is designed to provide these extensive data, because data for several rock types and fluid compositions may be obtained simultaneously. The data will provide a first estimate of sorption by Culebra rock, which will be used for performance-assessment model verification (Section 5.1.1.8) and for guiding retardation measurements by column experiments (Section 5.1.2.5). The data are also important for modeling radionuclide transport in the Culebra (Section 5.1.1.3).

5.1.2.5 Column Experiments for the Non-Salado

Description

This study will measure the retardation of radionuclides through Culebra rock for use in predicting radionuclide transport. Core samples will be taken from several boreholes throughout the Culebra. Each cylindrical sample, typically several inches in length, will be sealed on the cylindrical surface. A nonsorbing tracer in a brine solution containing a mixture of radionuclides corresponding to that which is expected from a repository breach will be injected into one unsealed end. The effluent concentrations of the nonsorbing tracer and radionuclides released from the other end will be measured as a function of time. The relative delay of breakthrough of each radionuclide in the effluent compared to that of the nonsorbing tracer will provide a direct measure of the chemical retardation of Culebra rock for the radionuclide and water composition being investigated. The measurement of radionuclide build-up in core samples may provide a direct confirmation of matrix diffusion.

Core has been extracted from the air intake shaft at two depths corresponding to different bedding planes in the Culebra. Experiments will be performed on these samples before proceeding with samples from other wells.

Justification

This study will demonstrate the extent of radionuclide retardation through Culebra rock and will produce data for performance-assessment model verification (Section 5.1.1.8). These laboratory studies are designed to provide a basis for modeling radionuclide transport in the Culebra (Section 5.1.1.3).

In addition, data from tests such as these column experiments have been stipulated by the State of New Mexico as required to justify using any non-zero value for retardation in Culebra rock in performance assessments.

5.1.2.6 Long-Core Tracer Tests for the Non-Salado

Description

This study is designed to provide the first large-scale radionuclide retardation measurements on Culebra materials. The experiments will use cores that are an order of magnitude larger than those typically used in laboratory experiments and, thus, will provide measurements on a scale closer to field conditions.

Experiments to determine radionuclide retardation will be performed in a controlled laboratory setting using column flow techniques. Usually, column flow experiments are performed on rock several inches in length. The question always remains, "Can one extrapolate sorption flow in cores several inches in length to the actual field flow path?" To help resolve this question and retain the advantage of studying radionuclides in a controlled laboratory setting, a long core (approximately 5 to 10 feet long) will be used. This approach allows researchers to conduct a large-scale experiment in a controlled laboratory setting. Furthermore, for cores of this length, it should be possible to monitor in situ the progress of some radionuclides through the core.

Justification

This will be the first large-scale laboratory experiment in which retardation studies can be performed on field rock with radionuclides that are present in TRU mixed waste. Thus, for the first time the question of how radionuclides flow and sorb over a long flow path can be addressed. Furthermore, the flow path can be monitored in the laboratory, which would be virtually impossible in the field. Combined with the small-scale laboratory column measurements (Section 5.1.2.1), these large-scale experiments are needed to provide a model of radionuclide retardation that can be scaled to the field for performance-assessment model verification (Section 5.1.1.8) and for the flow and transport model (Section 5.1.1.3).

5.1.2.7 Colloid Characterization and Transport for the Non-Salado

Description

The extent of radionuclide colloid formation and transport will be characterized. Radionuclide colloids may be composed almost entirely of colloidal-size radionuclide complexes, or of radionuclides sorbed on colloidal-size solid suspensate materials, or both. In either case, colloid migration may provide a mechanism for radionuclide transport or retardation.

Much work has been reported to determine the transport of dissolved radionuclides through porous media. However, insoluble materials, which can also transport radionuclides, may form small particles in solution. The particles may be formed when supersaturation conditions have been attained for a radionuclide. In addition, small clay particles or other nonradioactive materials may exist as suspended particles, and these particles may sorb radionuclides. If either type of colloids are present, radionuclides might be transported at the same rate as ground-water flow. Alternately, the colloids might be trapped in the Culebra by a "filtration" effect. Some quantitative measure of the importance of radionuclide colloids is essential to bound this transport mechanism.

Justification

Actinide transport via colloid migration may play an important role in increasing or decreasing the radionuclide migration rate. This transport will depend on how mobile the particles are relative to dissolved radionuclides. Potential colloid formation at the WIPP site has not yet been evaluated. Determination of the extent of radionuclide colloid formation and transport is needed to verify the performance-assessment model discussed in Section 5.1.1.8.

5.1.2.8 Test Design and Interpretation for the Non-Salado

Description

This study focuses on the design and interpretation of tests for measuring the primary physical parameters used in modeling ground-water flow and contaminant transport in the Rustler Formation. These parameters are used as direct input to both detailed mechanistic models (Section 5.1.2) and performance-assessment calculations.

Integration of the technical basis for double-porosity transport modeling is included under this study. Preliminary performance assessments (Bertram-Howery, et al., 1990) show that assuming fracture-only transport rather than double-porosity transport causes a significant shift in the complementary cumulative distribution function (CCDF) toward noncompliance. Although evidence for double-porosity behavior in the Culebra dolomite is substantial, it has been reported only in

separate reports, in isolation from other phenomena. An integrated analysis incorporating hydraulic testing, tracer testing, and double-porosity modeling has been completed and presented to numerous technical review groups, including the INTRAVAL project. Initial feedback from the INTRAVAL project includes the suggestion that data from alternate physical transport models (channeling models) should be explicitly tested against available data from field tracer tests, since it is likely that these models can also explain existing tracer test data. Also, the design of an additional tracer test should be explored to assure that the data provided by the test will be capable of distinguishing between double-porosity and channeling models of transport.

Justification

Given the large impact of fracture-only (including channeling) versus double-porosity transport assumptions, performance-assessment compliance modeling of contaminant migration scenarios requires an integrated rationale if a double-porosity model is to be used for transport modeling in the Culebra. Field tests that are designed to provide the basis for this rationale include both hydraulic tests (Section 5.1.1.4) and tracer tests (Sections 5.1.1.12 and 5.1.1.10).

5.1.2.9 Non-Salado Data Base for Performance Assessment

Description

This study focuses on integrating recommendations on Culebra/Rustler parameters and models for input to iterative performance-assessment calculation. This study involves review of previous performance-assessment modeling, review of the current status of Culebra flow and transport modeling (Section 5.1.1.2), integration with the current Culebra parameter data base (Sections 5.1.2.7), and development of specific recommendations for each annual iteration of performance-assessment calculations. This review and analysis will include periodic information exchange meetings with performance-assessment analysts during annual calculations. This study includes documenting recommendations and rationale for each year's performance assessment.

Justification

Iterative performance-assessment calculations require recommendations regarding parameter distribution and model implementation recommendations.

5.1.2.10 Sorbing/Retarding Tracer Tests for the Non-Salado

Description

Ongoing geochemical and Rustler flow modeling studies may indicate a need for field testing of the Culebra Formation with sorbing tracers. The current recommendation to design and execute a non-sorbing field tracer test to differentiate between double-porosity and channeling transport models provides the opportunity to conduct a sorbing tracer test as part of the non-sorbing field test.

Justification

Studies in Sections 5.1.1.2 and 5.1.1.7 investigate the adequacy of the hydrologic and transport data base for the formations overlying the Salado Formation. These studies have resulted in the recommendation that a sorbing tracer test be performed in the Culebra to investigate field-scale transport in the high-transmissivity zone in the Culebra dolomite. The information from these tests would be needed to investigate scale effects when applying data from column experiments of Sections

5.1.2.5 and 5.1.2.6 to the field-scale predictions of radionuclide retardation for the performance-assessment model verification (Section 5.1.1.3).

5.1.2.11 Data Base for Non-Salado Laboratory Studies

Description

The work discussed in Sections 5.1.2.1 through 5.1.2.7 has generated and will continue to generate large amounts of data on chemical and physical properties that will be used for transport modeling. Some data are stored in the aqueous solutions data base, but other data come from various reports. This study compiles all laboratory information for WIPP non-Salado flow and transport modeling into a comprehensive data base.

Justification

The laboratory studies in support of Rustler transport modeling will produce large amounts of data describing chemical, flow, and transport properties. These data are needed for the study on flow and transport modeling (Section 5.1.1.3). To maintain high quality assurance standards, these data need to be collected in a data base documenting their traceability.

Performance assessments must be based on traceable data. Therefore, critically evaluated, consistent, and traceable data must be collected in one data base for the performance-assessment model verification, (Section 5.1.1.8).

5.1.2.12 Non-Sorbing Tracer Tests for the Non-Salado

Description

The non-sorbing tracer test study focuses on performing field tracer testing with conservative (non-sorbing, non-reactive) tracers to quantify the primary physical parameters controlling solute transport within the Rustler Formation, particularly within the Culebra Dolomite Member. The important transport parameters of fracture porosity and fracture spacing are obtained from double-porosity interpretation of tracer tests. This type of testing has been performed at five locations at the WIPP Site. Final interpretation and reporting have been completed for the testing performed at two locations, while preliminary interpretations have been reported for a third. One of the most important recent results of this study is the complete interpretation and reporting of the tracer tests performed at three locations and completion of an integrated analysis of solute-transport mechanisms operative within the Culebra. Review of these interpretations and integrated analyses have led to the recommendation that an additional field tracer test designed specifically to differentiate between double-porosity and channeling transport models be performed. The non-sorbing parts of that tracer test will be performed under this study and will be combined with hydrologic testing (Section 5.1.1.4) and testing with a sorbing tracer (Section 5.1.2.10) in a three-phase field tracer test.

Geochemical studies (Section 5.1.2.10), Rustler transport modeling studies (Sections 5.1.1.2 and 5.1.2.8), and model validation studies (Section 5.1.1.7) may indicate a need for additional tracer testing of the Culebra or other Rustler members. That testing would be planned, performed, interpreted, and reported under this study.

Justification

Numerical performance-assessment modeling of contaminant-migration scenarios requires both a conceptual understanding of significant processes, mechanisms, and phenomena, and a defendable quantitative data base of pertinent transport parameters. These needs can only be met through a field experimental program directed at identifying significant processes and defining and quantifying important parameters. Tracer testing is designed to provide necessary information on fracture and matrix properties affecting solute transport.

5.1.3 Salado Hydrologic Properties Activity

The hydrologic properties of the host rock for the WIPP—the Salado Formation—must be adequately understood for both the human intrusion scenarios and the undisturbed scenario. In the case of human intrusion, the hydrologic characteristics of the Salado are important influences on the disposal-room environment over the long term. In the undisturbed case, Salado hydrologic characteristics in combination with the shaft seals determine the degree to which the planned repository can isolate the waste from the accessible environment. Key issues for both the undisturbed and disturbed cases are these questions: Can the formation provide significant quantities of brine to the waste rooms? Can the formation serve as a sink for significant quantities of waste-generated gas? In the absence of intrusion into the repository, will the Salado provide a barrier to the flow of fluids from the repository to the accessible environment for the next 10,000 years?

The Salado (see Figure 1-3) consists of stratified layers of relatively pure salt (halite), layers of argillaceous halite with varying clay content, clay seams, and anhydrite layers. The anhydrite layers appear to have higher permeability than the halite layers. Two important anhydrite layers, MB 138 and MB 139, lie within a few meters of the repository horizon. The stratification in the Salado is well defined and persists for long distances—on the order of kilometers. The nature of fluid flow in the halite and anhydrite layers is incompletely understood. Because pure halite is a "plastic" material, it has been widely believed that the entire Salado Formation is impermeable under lithostatic pressure. Some data contradict this belief. Results from several Salado testing programs have allowed the refocusing of testing efforts, ultimately aimed at answering the key questions stated above, to a series of more specific questions; namely, "What is the permeability, porosity and pore pressure in the anhydrite layers in the far field? To what extent do the anhydrite layers control flow in the Salado? Do the halite layers behave as a low-permeability continuum over large distances? Or is halite actually impermeable in its undisturbed state, with flow occurring only in regions near excavations with high deviatoric stresses? How is flow in the anhydrite layers influenced by the surrounding halite layers? Are there significant flow heterogeneities in the Salado and, if so, do sufficient interconnected pathways exist within the formation that an effective non-zero far field (or bulk) permeability can be defined? Will pre-existing fractures in the anhydrite layers open when pressurized by waste-generated gas and allow gas dissipation into the far field?" The studies described in this Section (5.1.3) support the technical approach for resolving these questions.

5.1.3.1 Salado Threshold Pressure

Description

Flow of waste-generated gas into the Salado Formation surrounding the repository will occur only when the gas pressure in the repository exceeds the sum of the formation near-field hydraulic (pore) pressure and the formation threshold displacement pressure. No measurements of Salado threshold displacement pressure exist: current multiphase modeling of waste-generated gas flow into the Salado

relies on extrapolating rock properties reported in the scientific literature for low permeability media. The validity of low permeability media as an analogous material has not been experimentally verified.

This study will develop experimental techniques to measure threshold displacement pressure for the Salado. Core extracted under pressure or other techniques may be used to validate laboratory results for in situ conditions.

Justification

Because no measurement of Salado threshold pressure exists, uncertainty in threshold displacement pressure values is large (estimates range from 0 to 50 Mpa) and may prevent a clear prediction of repository behavior in both undisturbed and human intrusion scenarios. Measurement of this Salado parameter will reduce uncertainty.

Threshold displacement pressure measurements taken in the laboratory are designed to provide data to support the development and evaluation of Salado models and performance-assessment calculations. In particular, measurements of threshold pressure will support performance-assessment calculations of the potential for waste-generated gas to escape from repository rooms.

Data from this study will be incorporated into the data base for Salado laboratory studies (Section 5.1.3.6) and integrated into the performance-assessment data base (Section 5.1.3.11).

5.1.3.2 Salado Relative Permeability

Description

Absolute or intrinsic permeability is a measure of the ease with which a single fluid will move through interconnected pores (one-phase flow). However, when dealing with the presence of more than one fluid (brine and gas, for the WIPP), relative permeability relationships must be considered. Relative permeability compares the ease with which one fluid will move through interconnected pore space when a second fluid is present as a function of saturation and the intrinsic permeability. Relative permeability is important in performance-assessment calculations because prediction of repository behavior (brine inflow to repository rooms and gas outflow to the formation) is strongly dependent upon this parameter.

No measurements of Salado brine/gas relative permeability exist. Multiphase modeling of waste-generated gas relies on extrapolating rock properties for other low permeability media reported in the scientific literature to the low-permeability media in the Salado. This study will develop experimental techniques to measure brine/gas relative permeability for the Salado. Because relative permeability is a function of the saturation of each fluid in the rock, relative permeability measurements will be made for a full range of saturation values. Pressurized core-extraction techniques will be developed if required (see Section 5.1.3.1).

Justification

Because no measurement of Salado brine-gas relative permeability exists, uncertainty in brine/gas relative permeability values is large and may prevent a definition of repository behavior in undisturbed and human intrusion scenarios. Measurements of this Salado parameter will reduce uncertainty.

The data from this study will be incorporated into the Salado data base for laboratory studies (Section 5.1.3.6) and integrated into the Salado performance-assessment data base (Section 5.1.3.11).

5.1.3.3 Salado Permeability Versus Stress

Description

This study will quantify changes in permeability as a function of stress/strain under confining pressures. These changes in permeability are observed at distances exceeding current estimates of the DRZ extent. Initial efforts will focus on developing and testing the permeability and stress/strain relationship.

Limited work has been done for halite and anhydrite. This task will develop experimental techniques and measure permeability changes as a function of stress/strain under given confining pressures.

Justification

The relationship between permeability and stress/strain is important for delineating the extent of an excavation-induced damage zone and radius of hydraulic influence. Excavation is known to affect halite and anhydrite and has the potential to increase fracturing and permeability far into the formation. Quantifying the permeability and stress/strain relationship will provide data to support the development and evaluation of Salado models and performance-assessment calculations and the interpretation of data from the permeability testing programs (Sections 5.1.3.12, 5.1.3.13, and 5.1.3.14).

Data from this study will be incorporated into the Salado data base for laboratory studies (Section 5.1.3.6) and integrated into the Salado performance-assessment data base (Section 5.1.3.11).

5.1.3.4 Salado Porosity

Description

This study will develop experimental techniques to measure porosity for the Salado Formation under varying stress conditions. Current modeling sensitivity results identify formation storativity, which is highly dependent upon porosity, as an important parameter for quantifying the effect of the rock matrix on brine inflow. Changes in porosity with changing stress conditions may help identify zones of excavation-induced damage. Such a stress/porosity relationship may aid in evaluating brine flow into waste storage rooms and brine and/or gas flow out of waste storage rooms. Porosity measurements will also support the development of correlations to predict threshold pressure and two-phase parameters from existing data.

Salado porosity is currently inferred from data from other experimental programs in which measurements were made under static stress conditions. Stress conditions in the vicinity of excavations change with time as the disturbed rock zone grows.

Justification

It is important to quantify the magnitude of the stress-related change in porosity in order to support performance-assessment calculations of the rate at which brine will enter or leave waste storage rooms. For example, in the case of Room Q (see Figure 1-4) actual brine inflow is significantly less than that predicted using the Darcy-radial flow model. It is currently unknown whether the model is

incorrect or whether the "missing" brine is stored in the increased interconnected pore space created by the stress.

Data from this study will be provided to the Salado data base for laboratory studies data base (Section 5.1.3.6) and integrated into the Salado data base for performance assessment (Section 5.1.3.11).

5.1.3.5 Salado Brine Chemistry

Description

The chemistry of brines seeping into vertical and subhorizontal boreholes in the WIPP underground is being monitored through time for concentrations of major constituents. Systematic study of the brine chemistry as a function of time and borehole location could yield information on brine inflow mechanisms and contamination of repository horizon brines with water from underground operations. This study extends the scale of previous work and also examines the influence of time and borehole age on the brine composition.

Justification

Brine chemistry can provide information on the extent of chemical composition heterogeneity in the Salado, which can indicate whether brine in the Salado occurs in isolated pockets or as a continuous phase in a permeable medium. Compositions also yield information about the extent of fracturing in the marker beds due to the formation of a DRZ. This study is designed to provide data necessary for the model development studies described in Section 5.1.3.8.

5.1.3.6 Data Base for Salado Laboratory Studies

Description

This study is designed to provide data sets from which parameter distributions and modeling recommendations will be formulated for the performance-assessment data base. Data sets are also supplied to international collaborative groups. The data sets compiled in this study include data (Sections 5.1.3.1 through 5.1.3.6) that will be used to derive threshold pressure, relative permeability, permeability variation with stress, porosity, brine chemistry, brine physical properties, gas solubility, and retardation.

Justification

This study will set up and maintain a data base containing data sets determined from Salado laboratory experiments (Sections 5.1.3.1 through 5.1.3.5). This data base will be integrated with the Salado field-studies data base (Section 5.1.3.16) to provide a documented basis from which to form parameter distributions and modeling recommendations on the Salado for the performance-assessment data base (Section 5.1.3.11). The laboratory data base will contain raw and processed data, references used in data reduction and analysis, documentation and recommendations for their intended use, data limitations, error and uncertainty analyses, and statistical parameter distributions. Raw data are also provided to international collaborative groups, such as the International Project to Study Validation of Geosphere Transport Models (INTRAVAL).

5.1.3.7 Repository-Scale Multiphase Modeling and Sensitivity Studies

Description

This task is designed to provide an integrated analysis and predictive models characterizing hydrologic processes and process coupling that control repository pressurization and gas-driven contaminant transport in response to waste-generated gas. Pertinent hydrologic, geologic, mechanical, and gas source-term information (from studies described in Sections 5.3.1.2, 5.2.1.5, 5.1.3.1, 5.1.3.2, 5.1.3.12, 5.1.3.13, and 5.1.3.14) is assembled and evaluated. Conceptual models describing various components of the repository system are developed and implemented as numerical models. Sensitivity simulations are used to identify important processes and parameters. These analyses are designed to provide a detailed understanding of the physical processes that control repository pressurization and gas-driven contaminant transport under various conditions, provide feedback to ongoing experimental programs, and provide a technical basis for formulating simplified models for use in performance-assessment calculations.

Work completed under this task includes an assessment of the role of threshold pressure in controlling flow of waste-generated gas into the bedded salt surrounding the repository and preliminary fixed-geometry, gas-flow simulations. Preliminary simulations examined the impact of threshold pressure, gas dissipation through interbeds, room closure, and variable gas-generation rates.

This study involves a collaborative effort with the work described in Section 5.2.1.5 to model the room closure process (i.e., the creep closure of the surrounding salt formation onto the waste and backfill), fully coupling closure with two-phase fluid flow, including gas flow along interbeds. Current modeling examines single-room behavior and will be followed by analysis of multi-room interactions, human intrusion, and gas-driven contaminant migration.

Justification

Evaluation of the hydrologic response of the repository system to waste-generated gas is needed to provide the technical basis for performance-assessment modeling of repository behavior. For example, the current performance-assessment repository model uses a simplified "equivalent radial panel" for multiphase simulations, yet the technical foundation does not exist for scaling calculations to a radial panel, for estimating average properties that include both rooms and salt pillars, and for coupling far-field gas flow and room closure. In collaboration with technical issues posed by the disposal-room model and data base study (Section 5.2.1.5), these technical issues are being addressed by first analyzing single room response (both an isolated room and a room in an infinite array) and then analyzing multiple-room interactions and panel-scale behavior. Important model information on gas-generation rates will come from laboratory and bin test programs. Data on physical parameters for multiphase fluid models comes from laboratory and field tests of hydrologic properties and fluid flow mechanisms in the Salado.

5.1.3.8 Model Development for the Salado

Description

Mechanisms that allow brine to seep from the Salado Formation into the repository excavation are incompletely understood. The objective of this study is formulation and application of models for flow and transport in the Salado. Model formulation is combined with sensitivity studies and studies described in Section 5.1.3.9 to depict the numerous proposed mechanisms by which brine can enter the repository and to experimentally confirm or dismiss those mechanisms.

Capillary pressure and relative permeability, represented by two-phase characteristic curves. can have a significant effect on repository pressurization and gas flow for the undisturbed scenario. Therefore, studies will be undertaken to understand the important phenomena involved. In addition, other factors which may be important, such as viscous and capillary fingering, will be investigated.

Justification

Adequate understanding of the mechanisms by which brine enters the repository from the Salado is needed to support predictions of repository behavior. Formulation of alternative models for brine inflow will allow designing tests (Section 5.1.3.9) that are capable of discriminating between alternative models for brine flow.

Two-phase characteristic curves have been inferred from analog materials and are subject to a high degree of uncertainty because no theoretical studies or measurements have been made on actual Salado materials. These curves are used to perform the multi-phase simulations (Section 5.1.3.7) and are also used in performance-assessment calculations. Therefore, an understanding of the important phenomena in the two-phase characteristic curves is needed.

5.1.3.9 Test Design and Interpretation for the Salado

Description

Brine inflow and permeability data are being collected (Sections 5.1.3.12 through 14) to evaluate brine inflow models (Section 5.1.3.8). To design and interpret tests and to guide the design of future tests for measuring appropriate parameters, studies are being performed to determine the sensitivity of various model parameters, including two-phase flow variations. Sensitivity studies for an open borehole (Section 5.1.3.13) have been completed, and similar studies for permeability tests (Sections 5.1.3.12 through 5.1.3.14) will be performed. Standard test interpretation schemes are being defined for consistent evaluation of inferred parameters.

Justification

Brine inflow into the repository is coupled with the gas generation rate from the waste and subsequent repository pressurization. A model is needed to evaluate the brine inflow rate into the repository. In addition, the brine inflow and permeability tests must measure the appropriate parameters to differentiate between various conceptual models as guided by the sensitivity studies. These tests must be interpreted in a consistent manner to allow comparison of inferred parameters.

Studies described in Sections 5.1.3.12 through 5.1.3.14 acquire brine inflow and permeability data for use in model development. This task is to interpret and design future tests to obtain the necessary information for model development (Section 5.1.3.8). This information is also used in the repository-scale multiphase model (Section 5.1.3.7) and is part of the international validation and collaboration study (Section 5.1.3.10).

5.1.3.10 Validation and International Collaboration for Salado Model

Description

This study will support the WIPP salt test case submitted to INTRAVAL for Phase II and other international collaborative groups. Studies include attendance and presentations at meetings, discussion of model validation (Section 5.1.3.8), and participation in another test case in the Salt

Working Group. The WIPP salt test case was accepted by the INTRAVAL for Phase II in February 1990. Phase II work began in April 1991 and will last three years.

An exchange is currently being proposed to foreign scientists for the joint development of methods for the measurement of two-phase flow properties in halite. The proposed joint studies are described in 5.1.3.1 and 5.1.3.2.

Justification

Performance-assessment mechanistic models should be validated to the extent possible. Publication and the concomitant scientific review of data and models are the processes necessary to ensure adequate model validation.

INTRAVAL participation provides review of WIPP data and models of brine inflow by international teams of experts. In addition, it allows WIPP scientists to participate in discussions of approaches to model validation.

5.1.3.11 Salado Data Base for Performance Assessment

Description

This study focuses on interpreting experimental data to formulate integrated recommendations on Salado parameters and models for input to iterative performance-assessment calculations. This study incorporates a review of previous performance-assessment modeling, a review of the status of Salado flow and transport modeling described in Sections 5.1.3.7 and 5.1.3.8, an integration with the current Salado-parameter data base (Sections 5.1.3.6 and 5.1.3.16), and the development of specific recommendations for performance-assessment model parameters for each iteration of performance-assessment calculations. This review and analysis will include periodic information exchange with the performance-assessment team during the calculation cycle. This study includes documentation of the recommendations and rationales for each performance assessment.

Justification

Iterative performance-assessment calculations require information in the form of parameter distributions and model implementation recommendations. Information on Salado models comes from studies described in Sections 5.1.3.7 and 5.1.3.8 and from interpretation of field-scale hydrologic tests (Sections 5.1.3.12 through 5.1.3.15). Distribution functions for performance-assessment model parameters are derived by interpreting field and laboratory data with an appropriate set of models in the presence of known or estimated data uncertainty.

5.1.3.12 Salado Far-Field Permeability Testing

Description

Arrays of up to five holes are planned for five locations distributed throughout the WIPP underground experimental area. These arrays include holes drilled vertically upward or downward, horizontally, or diagonally upward or downward. Bottom-hole permeability tests are performed in each hole using a double-packer test tool with a guard zone. The permeability tests include pressure-pulse tests and/or constant-pressure flow tests. Withdrawal tests are performed in preference to injection tests whenever possible. All test zones are instrumented with pressure transducers, thermocouples, radial linear variable differential transformers (to measure borehole closure), and axial linear variable

differential transformers (to measure tool movement in the hole). Guard zones are instrumented with pressure transducers and thermocouples. Packer pressures are also monitored at all times.

Pulse-withdrawal and/or constant-pressure flow testing have been completed in 22 zones in ten boreholes. Data suggest that relatively pure halite may have no measurable permeability or pore pressure, while argillaceous and/or polyhalitic halite have permeabilities in the range of 10^{-21} to 10^{-20} m^2, and anhydrite interbeds have permeabilities on the order of 10^{-19} or 10^{-18} m^2. Data also suggest that the WIPP excavations may have caused partial depressurization of the rock to a distance of as much as six meters from the excavations.

Justification

The rate of brine seepage into the excavations will be largely controlled by far-field permeability. Brine inflow could strongly influence the degree and rate of consolidation of backfill and the final state of the closed rooms. The far-field permeability will also directly affect the rate at which the fluid pressures within the WIPP will re-equilibrate after closure. This study supports field testing to measure the permeability and pore pressure within the Salado around the WIPP excavations.

The data provided by this study will be used for repository-scale multiphase modeling (Section 5.1.3.7), disposal-room performance modeling (Section 5.2.1.5), and repository and shaft modeling systems (see Section 3.1.1.2).

5.1.3.13 Small-Scale/Intermediate-Scale Brine-Inflow Experiments

Description

Brine inflow is being measured in 17 boreholes ranging from 5 to 90 cm in diameter. The current brine inflow model reasonably approximates the brine inflow response of eleven of these boreholes over the early portion of each borehole's history. The model less often closely approximates the more recent data taken from boreholes under 10 cm in diameter, and does not accurately predict yields in boreholes greater than 10 cm. Processes not considered in the current model may influence the yield of brine to some boreholes. Additional measurements in the existing boreholes and new experiments are needed to investigate these processes.

To develop a predictive mechanistic model, the far field processes influencing brine inflow need to be measured in the field. These processes may include heterogeneity and anisotropy within and across stratigraphic layers; multidimensionality of the true borehole configuration; intersection of the borehole with pre-existing, healed, discrete fractures in the marker beds; and the complex interactions between salt deformation, brine flow, and multiphase flow. Although the current experiments provide useful information, additional experiments are needed to identify and quantify the effects of numerous processes that may influence brine inflow.

Justification

Brine inflow may significantly affect overall repository performance. Brine may corrode waste containers and dissolve waste materials, creating a source pool of potentially mobile radionuclides. In addition, brine may increase gas generation rates, and the presence of brine would impact the reconsolidation of crushed-salt seal components. Quantitative predictions of brine-flow behavior are needed to assess waste package and overall repository performance, as well as the development of the repository seals.

Currently, data are being analyzed to derive permeability and hydraulic diffusivity estimates and uncertainties for the performance-assessment model. The data are incorporated into the field studies data base (Section 5.1.3.16) and the parameter estimates are incorporated into the performance-assessment data base (Section 5.1.3.11). Moreover, additional small- and intermediate-scale brine-inflow experiments are needed to provide data for the development (Section 5.1.3.8) and validation (Sections 5.1.3.10 and 5.1.3.17) of a predictive mechanistic model for brine inflow to WIPP excavations that can be incorporated into the performance-assessment model.

5.1.3.14 Large-Scale Brine-Inflow Experiments

Description

Room Q (see Figure 1-4), mined in 1989, is cylindrical, 357 feet long and 9.5 feet in diameter. Brine flow into the room is being determined using relative humidity measurements and by collecting and weighing brine accumulations in the room. Ground-penetrating radar, resistivity array surveys, and room closure measurements have been made and will be analyzed to provide information on brine flow in the formation around Room Q. Fifteen borehole tests in the formation around Room Q are providing data on hydrologic parameters, including pore pressure and permeability in, above, and below the disposal horizon in halite and anhydrite beds and clay seams. In addition to these experiments, small shallow sumps or boreholes may be created in the floor of the room to facilitate remote brine collection.

The large-scale brine inflow experiments test the scale-up capability of brine inflow models, sample a large representative volume of rock, and characterize the disturbed rock zone around Room Q. This study also determines the near- and far-field pore pressure distributions, infers domains of interconnected flow from the pore pressure data, tests the brine-inflow model by comparing predicted and measured pore-pressure distributions, and establishes pore-pressure boundary conditions for model calculations of brine inflow.

Justification

It is important to test the capability of the brine-inflow model to predict the rate and quantity of brine inflow into openings in the Salado ranging in size from small boreholes to disposal rooms. It is important to be able to differentiate between brine-inflow mechanisms while also evaluating models. The presence of fractures and heterogeneities in the host rock could obscure test results. The cylindrical shape of the room, however, is expected to minimize fractures and partings. Resistivity measurements and ground-penetrating radar surveys may be used to evaluate the fracture conditions in the salt around the openings. Measurement of pore pressure and permeability in the host rock surrounding Room Q may provide information pertinent to understanding the flow mechanisms in the Salado Formation.

Data from this study will be incorporated into the Salado data base for field studies (Section 5.1.3.16) and will be integrated into the performance-assessment data base (Section 5.1.3.11).

5.1.3.15 Threshold-Pressure Testing of Marker Bed 139

Description

The threshold-pressure testing study supports planning, performance, and interpretation of a threshold pressure test of MB 139 (see Figure 1-3). The pressure from the marker bed will be allowed to stabilize in the brine-filled hole. The brine will then be replaced with gas and the pressure required

to drive the gas into the marker bed will be measured. The incremental pressure above the existing brine pressure required to displace brine within the pores of the rock and establish a flow pathway for gas is called the threshold pressure. The test will be conducted in a borehole where previous hydraulic testing of MB 139 has shown that location to have a brine pressure close to that believed to be present in the far field.

Justification

Repository-scale multiphase modeling (Section 5.1.3.7) has shown anhydrite interbeds such as MB 139 to be the principal avenues for gas flow away from the repository. Information on the threshold pressures of the interbeds is necessary to evaluate the rate at which gas generated within the repository might be dissipated through the anhydrite interbeds. The information provided by this study will be used for repository-scale multiphase modeling (Section 5.1.3.7), disposal-room performance modeling (Section 5.2.1.15), and repository and shaft systems modeling (see Section 3.1.1.2).

5.1.3.16 Data Base for Salado Field Studies

Description

This study supports the summation of data derived from field experiments, and the compilation of these data into a data base for performance assessment. This data base is integrated with the laboratory studies data base (Section 5.1.3.6) to provide recommendations on Salado hydrologic parameters for the performance-assessment data base (Section 5.1.3.11) and international collaborative groups (Section 5.1.3.10). The data base will contain raw and processed data, references used in data reduction and analysis, documentation and recommendations for its intended use, data limitations, error and uncertainty analyses, and statistical parameter distributions.

Justification

Parameter values derived from Salado field tests are needed for performance-assessment calculations. The parameter values are provided in the form of distribution functions. Models for use in the compliance calculations will also be recommended. Data from the field experiments will be placed in the Salado hydrology field studies data base and used to generate the distribution functions which will be incorporated into the performance-assessment data base. The parameters include permeability of different Salado strata to brine, and the distribution of formation pore pressures, threshold pressures, and effective porosities.

5.1.3.17 Benchmarking of Mechanistic and Performance-Assessment Models

Description

Due to computer time requirements, performance assessment requires hydrologic and computational models for the Salado that are different from the detailed mechanistic models. Verification of the performance-assessment hydrologic and computational models is needed to ensure the consistency of results of the various calculations being performed.

Justification

Performance-assessment calculations employ fast-running hydrologic models and computer codes to meet computer time restraints. These models and codes are necessarily less sophisticated than the

models and codes used in detailed calculations. To evaluate the adequacy of the performance-assessment models and codes, comparison and benchmarking are needed.

In addition to differences in the construction of computer codes, the performance-assessment models are calculationally more efficient than the mechanistic models. Differences include, but are not limited to, less detailed nodalization and greater simplification of physics models for a given computer program. To ensure accuracy with the performance-assessment models, any differences in the results from the models will be evaluated.

This study provides the only link, other than the studies described in Section 5.2.1.5, between the calculational efforts in the repository-scale multiphase modeling (Section 5.1.3.7) and the performance-assessment hydrologic modeling and repository and shaft system modeling (see Section 3.1.1.2).

5.1.4 Salado Transport Activity

Transport of radionuclides or hazardous materials into and through the Salado Formation occurs when brine and gas flow from the waste rooms through the disturbed rock zone surrounding the waste disposal rooms. It is likely that the preferred travel path through the undisturbed Salado will be through the anhydrite layers, specifically, MB 138 and MB 139 and anhydrite beds A and B (see Figure 1-3). Transport in the liquid phase is the predominant focus of research for migration of radionuclides and hazardous materials. However, if a significant amount of gas is generated by the waste, gas-phase transport will be important for potential transport of VOCs toward the accessible environment. Thus major questions are centered around the nature of transport in the marker beds: What is the importance of capillary fingering or channeling to the flow of waste generated gas from the repository? Is flow primarily fracture flow? Is double porosity present? What retardation mechanisms are expected to operate in the marker beds?

The technical approach for addressing this issue is to conduct laboratory and field-scale experiments to characterize transport in the anhydrite layers within the Salado. Laboratory testing will obtain marker bed data (gas and fluid transport), focusing on demonstration and characterization of capillary finger formation, fracture flow, and matrix diffusion in the anhydrite layers. A field transport test is planned for MB 139. Fundamental brine and rock chemistry information will be obtained if existing site characterization data are insufficient to identify the operative retardation mechanisms. The studies described in this Section (5.1.4) are designed to provide the data necessary to develop transport models for use in performance-assessment calculations and other system-scale sensitivity studies.

5.1.4.1 Gas Solubility in Salado Brines

Description

The solubility of gases (hydrogen and methane) likely to be produced by radiolysis and decomposition of the waste will be measured as a function of aqueous composition. A literature survey of gas solubilities in sodium chloride brines has been completed and indicates that gas solubilities decrease by about a factor of three to five as the amount of sodium chloride varies from zero to near saturation (Cygan, 1991). No data have been found for hydrogen solubility in these systems at high pressures. Although data from the literature for sodium chloride brines provide an estimate of gas solubility in WIPP brines, the complex chemistry expected in the room environment might result in significantly different gas solubilities. Under this study, experiments will be conducted to determine the interaction of hydrogen, oxygen, and methane with the major solutes in WIPP fluids, including sodium, potassium, calcium, magnesium, chloride, sulfate, carbonate, and boron. These experimental

studies are designed to provide data necessary for calculating gas solubilities under the wide range of expected conditions in disposal rooms.

Justification

Gas solubility in repository brines could have a significant impact on pressure buildup in the repository and thus on radionuclide or volatile organic carbon release into the marker beds in the Salado. The importance of gas solubility in repository brines has not yet been determined by performance-assessment calculations. Accurate values for gas solubility in waters with compositions similar to those in the disposal rooms are necessary to quantify the rate of gas buildup and release into the marker beds. This study is designed to provide data necessary for the modeling and sensitivity studies described in Section 5.1.3.7.

5.1.4.2 Retardation in the Salado

Description

This study will assess the importance of gas-phase radionuclide transport and retardation through Salado rock. Transport in the liquid phase is the predominant focus of research for migration of radionuclides. However, if a significant amount of gas is generated by the waste or the migration path is through an unsaturated zone, gas-phase transport may become an important pathway for radionuclide release. Several gas-phase isotopes—iodine-129, carbon-14, radon-222, and hydrogen-3—are regulated by 40 CFR 191.13. Gas-phase transport of a decay chain in which some members are not gaseous introduces an additional complication. These nongaseous members may be transported in the liquid phase; therefore, gas and liquid transport may be coupled processes.

Previously developed models of this process will be used to estimate the potential impact of gas-phase transport. Bounds will also be established on the importance of the following processes that are not included in current models: (1) coupled gas-phase and liquid-phase transport, (2) transport in more than one dimension, (3) decay chains, (4) convective transport, and (5) pressure and temperature effects.

Justification

An assessment of gas-phase radionuclide transport is needed to support the performance-assessment model verification (Section 5.1.1.8).

5.1.4.3 Tracer and Transport Testing in the Salado

Description

This study supports planning, performance, and interpretation of a tracer test in MB 139 below Room C2 (see Figure 1-4) in the WIPP experimental area. Conservative (non-reactive) tracers will be injected into one or more holes penetrating MB 139 and the arrival of those tracers will be monitored at one or more other holes undergoing constant-pressure fluid withdrawal. This test is designed to provide information on the nature of the flow field within the marker bed (continuum vs. channelized), on the effective porosity of the rock, and on physical retardation mechanisms such as matrix diffusion.

Justification

Repository-scale multiphase modeling (Section 5.1.3.7) has shown anhydrite interbeds such as MB 139 to be the principal avenues for flow of brine or gas, or both, away from the repository. For performance assessment to evaluate whether hazardous or radioactive contaminants can reach the accessible environment through these anhydrites, information on the transport properties of anhydrite must be collected. These data will be used for repository-scale multiphase modeling (Section 5.1.3.7), disposal-room performance modeling (Section 5.2.1.5), and repository and shaft systems modeling (see Section 3.1.1.2).

5.1.4.4 RCRA Constituents Retardation in the Salado

Description

Movement of hazardous constituents can occur by transport of contaminated liquid or gas along drifts and shafts, or along interbeds within the Salado. Retardation of hazardous constituents (the reduction of transport rates relative to the average fluid flow velocity) can occur along flow paths by chemical and/or physical processes. This study addresses the extent that hazardous constituents will be retarded by chemical adsorption processes along potential flow paths from the disposal rooms to the unit boundaries. Effective retardation factors for liquid-phase transport of heavy metals and hazardous organics, and effective retardation factors for gas-phase transport of organics will be determined. This information will be used to determine hazardous constituents transport times and concentrations at the unit boundary.

Literature surveys, and possibly follow-on experiments, are required to estimate sorption coefficients for hazardous constituents along potential flow paths from the waste-emplacement rooms to the unit boundary. Hazardous constituents may be transported as brine contaminated with organics and/or metals, or they may be transported as a gas mixture (carbon dioxide, hydrogen, methane, etc.) contaminated with volatile organics. Transport simulations will be used to determine the dominant flow paths to focus laboratory experiments on critical needs. Batch and/or column sorption experiments will be performed, if necessary, with contaminated brine to determine liquid-phase retardation factors for backfill and anhydrite. Gas chromatography experiments will be performed, if necessary, using a carrier gas that is spiked with organic vapors to determine gas-phase retardation factors for backfill and anhydrite.

Justification

Values for hazardous constituents retardation coefficients are not currently available. RCRA compliance models can make a simplifying and conservative assumption that no retardation occurs, or alternatively can make a more realistic assumption that retardation will occur. If the more realistic approach is taken, some combination of literature surveys, theoretical arguments, and laboratory experiments will be required to provide retardation coefficients.

5.2 Repository Design and Engineered Barriers

Both the design of the planned repository and the engineered barriers affect the performance of the repository system. The repository design is completed and a significant portion of the facility has been constructed; hence, design features related to performance are relatively well established. These include the layout of the planned repository and the operations that could impact performance (number of panels, number and sizes of rooms in each panel, amount and distribution of waste emplaced in each room, footprint of the repository, distance to marker beds, etc.). Performance

evaluations of engineered barriers will predict the behavior of the disposal room and efficacy of the seals placed in shafts, drifts, panel entries, and boreholes.

The principal products of the seal activities are feasible designs that meet performance requirements, performance models for the seals, and the associated data base. Numerous interactive studies are necessary to produce the designs and models.

Disposal room performance evaluations (Section 5.2.1) will simulate the coupled mechanical, hydrological, and chemical processes associated with the waste and the surrounding host rock. Performance evaluations of the seal systems (Section 5.2.2) will consider the disposal phase and the period after decommissioning to determine whether these systems perform the short- and long-term functions required of them. For purposes of seal system discussions in this Section (5.2), the phrase "long-term" identifies the time period that begins when the emplaced salt components become effective seals (approximately 100 years after seal emplacement) and continues throughout the disposal regulatory period. "Short-term component" identifies those components required to be effective prior to reliance upon the long-term components. These evaluations depend upon understanding and predicting the behavior of the seal materials (crushed salt, concrete, clay, grout, and other materials) in the WIPP environment. The performance evaluations will be based on detailed designs of the seal systems (Section 5.2.3). Only through such designs (and associated demonstrations) can emplacement feasibility be established. Those demonstrations also increase confidence in assumptions made in performance-assessment calculations related to the initial performance and behavior of the seals.

Two important supporting technology areas related directly to the performance of the engineered barriers are evaluations of the permeability of the disturbed rock zone (Section 5.2.4) around the excavation and evaluation of the closure of shafts, drifts, and boreholes (Section 5.2.5). Both of these activities are designed to provide analytical models of the behavior of the host rock that are critical parts of assessing potential fluid flow past seal components or fluid flow related to the performance of the disposal room.

Each of the ongoing activities is supported by several studies that are listed in Table 5-2. Studies are further categorized as a laboratory test (L), field test (F), design task (D), modeling study (M), or protocol function (P). Test plans are prepared for laboratory tests and field tests; these are also listed in Table 5-2. Individual plans are typically prepared for all tests with waste and for major non-waste field tests. Generic plans are prepared for laboratory and field studies that do not warrant individual test plans. Test plans may be revised or supplemented as tests evolve.

5.2.1 Disposal Room Performance Activity

Strongly coupled mechanical, hydrologic, and chemical processes are likely to have a profound impact on the waste-room environment. Closure of the disposal rooms begins immediately after excavation, as the salt surrounding them begins to creep closed. Simultaneously, intercrystalline brine begins to migrate toward the disposal room. After waste emplacement, gas generation is expected initially to be due largely to radiolysis and microbial activity. Once brine enters the room and contacts the TRU mixed wastes, however, gas generation rates of all three major gas generation mechanisms (corrosion, microbial gas generation, and radiolysis) are expected to increase. The current understanding of room consolidation is that the room will continue to creep closed until the total gas pressure or mechanical backpressure from the waste and backfill stops consolidation and brine inflow. The room pressure can then slowly approach the pressure of the lithostatic overburden, in an equilibrium condition. However, continued gas generation after equilibrium would require that the room expand; that excess gas migrate away from the room along existing gas-migration paths; or that fractures are induced in the halites, interbeds, or anhydrite marker beds within the host rock of

Table 5-2. Repository Design and Engineered Barriers Activities, Supporting Studies, and Associated Test Plans

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.2.1	Disposal Room Performance Activity		
5.2.1.1	Properties of Disposal-Room Backfill	L	Test Plan: Disposal Room Backfill Properties Studies (To be developed).
5.2.1.2	Mechanical and Permeability Properties of Waste	L	Test Plan: Waste Mechanical and Permeability Properties Studies (To be developed).
5.2.1.3	Mechanical Model of Disposal-Room Backfill	M	NA
5.2.1.4	Model of Waste Mechanical Properties	M	NA
5.2.1.5	Disposal-Room Model and Data Base	M	NA
5.2.1.6	Model of Engineered Alternatives	M	NA
5.2.1.7	Tests of Simulated Disposal Rooms (Rooms T and J)	F	Test Plan Appendix: WIPP Simulated RH TRU Waste Add-on Tests, M. A. Molecke and D. E. Munson, 1987. Test Plan: WIPP Materials Interface Interactions Test (MIIT), M.A. Molecke and G. G. Wicks, 1986. Test Plan: WIPP Simulated CH and RH TRU Waste Tests: Technology Experiments (TRU TE). M.A. Molecke, 1986.
5.2.1.8	Feasibility Analysis for Room-Scale Test	M/F	This study is currently a modeling/analysis effort. If a field test or demonstration is determined to be necessary, an appropriate Test Plan or Field Operations Plan will be prepared.

Table 5-2. Repository Design and Engineered Barriers Activities, Supporting Studies, and Associated Test Plans (Continued)

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.2.2	Shaft, Drift, and Borehole Seals Performance Activity		
5.2.2.1	Development of Materials for Short-Term Seals	L	Test Plan: Laboratory Tests in Support of the Rock Mechanics and Sealing Programs (To be developed).
5.2.2.2	Development of Materials for Crushed-Salt Seals	L	See 5.2.2.1
5.2.2.3	Data Base for Seals Materials	P	NA
5.2.2.4	Model of Seals Components	M	NA
5.2.2.5	Sealing System Integration	P	NA
5.2.2.6	Small-Scale Tests of Seals Performance	F	Test Plan: Sealing of the Disturbed Rock Zone (DRZ), Including Marker Bed 139 (MB139) and the Overlying Halite, Below the Repository Horizon, at the Waste Isolation Pilot Plant; Small-Scale Seal Performance Test-Series F, E.H. Ahrens, 1992. Addendum to Test Plan: Small-Scale Seal Performance Tests (SSSPT), R. Finley, 1992. Test Plan: Appendix C, Small Scale Seal Performance Tests, J.C. Stormont, 1986. Test Plan: Appendix B, Small Scale Seal Performance Tests (SSSPT), J. C. Stormont, 1985b. Test Plan: Small Scale Seal Performance Tests (SSSPT), J. C. Stormont, 1985a.
5.2.2.7	Large-Scale Testing of Seals	F	Test Plan: Large Scale Seals Testing (To be developed).
5.2.2.8	Borehole Plugging Tests	F	Test Plan: Borehole Plugging Tests (To be developed).
5.2.3	Shaft, Drift, and Borehole Seals Design Activity		
5.2.3.1	Seal Design and System Model	D	NA
5.2.4	Disturbed Rock Zone Permeability Activity		
5.2.4.1	Study of Material and Fracture Properties	L	See 5.2.2.1
5.2.4.2	Disturbed-Rock-Zone Mechanisms	L	See 5.2.2.1
5.2.4.3	Kinetics of Fracture Healing in Salt	L	See 5.2.2.1
5.2.4.4	Mechanical Model of Excavation Effects in the Disturbed Rock Zone	M	NA
5.2.4.5	Characterization of the Disturbed Rock Zone	F	Test Plan: Disturbed Rock Zone Characterization, R. Finley (In preparation).
5.2.4.6	Geophysics of the Disposal System	F	Field Operations Plan (FOP) for Time Domain Electromagnetic (TDEM) Surveys at the Waste Isolation Pilot Plant (WIPP) Site, Blackhawk Geoscience, Inc., 1991.
5.2.4.7	Hydrofracture Studies of the Anhydrite Beds	F	Test Plan: Hydraulic Fracturing and Hydrologic Tests in Marker Beds 139 and 140, W. R. Wawersik and R. L. Beauheim, 1991.

Table 5-2. Repository Design and Engineered Barriers Activities, Supporting Studies, and Associated Test Plans (Concluded)

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.2.5	Shaft, Drift and Borehole Closure Activity		
5.2.5.1	Distribution Functions for Creep Parameters	L	See 5.2.2.1
5.2.5.2	Validation, Documentation, and QA for the Rock-Mechanics Data Base	P	NA
5.2.5.3	Development of Salt Constitutive Model	M	NA
5.2.5.4	Development of Fracture Constitutive Model	M	NA
5.2.5.5	Development of Numerical Code	M	NA
5.2.5.6	Verification and Validation of Code	M	NA
5.2.5.7	Performance of Air Intake Shaft	F	Addendum to Test Plan: Air Intake Shaft Performance Test, F. Gelbard, 1991. Test Plan: Air Intake Shaft Performance Tests, Appendix 17, B. A. Luke, 1990. Test Plan: Air Intake Shaft Performance Tests, R.V. Matalucci, 1987.
5.2.5.8	Intermediate-Scale Borehole Test	F	Test Plan: Intermediate Scale Borehole Test, D. E. Munson, 1989.
5.2.5.9	Panel Structural Test	F	Test Plan: Panel Structural Test (To be developed).
5.2.5.10	Test of Thermal and Structural Interactions	F	Test Plan: Heated Axisymmetric Pillar, T. M. Torres, 1983.
5.2.5.11	Integration of Rock-Mechanics Studies	P	NA
5.2.5.12	Mine-Support-System Technology and Demonstrations	M/F	See 5.2.1.8

1. D = Design Task
   F = Field Study
   L = Laboratory Study
   M = Modeling Study
   P = Protocol (data base management, integration of studies, etc.)

2. Test Plans are prepared only for laboratory and field tests
   NA: Test Plans are not applicable to Design, Modeling, and Protocol studies

the Salado Formation surrounding the disposal rooms, thus creating migration paths for gas (and brine) to move away from the disposal room.

The disposal-room model describes the disposal-room porosity and the permeability of the waste and backfill as functions of time, as well as examining the sensitivity of Salado fluid flow to the gas generation and disposal room conditions. Information concerning fracture formation and propagation as a function of pressure, as well as any pronounced stress effects on hydrologic properties are also of interest. The transfer of information from the disposal-room model into the performance-assessment process may be accomplished by incorporating various portions of the model directly into performance-assessment models, if the disposal room models are computationally efficient. This direct transfer is unlikely, however, because the strong coupling among the various processes involved in room response make the overall model inefficient for the iterative analyses used in performance assessment. Instead, redefinition of the disposal room model and related information for purposes of performance assessment, in the form of more efficient models, such as the three-phase model or data tables, is likely to be necessary.

The current research is intended to provide answers to the following questions. What are the physical couplings among room creep (including salt and anhydrites), gas generation, gas movement/dissipation, and brine inflow/outflow? To what extent will gases dissipate into the Salado and marker beds with and without enhanced permeability in response to gas generation? To what extent does brine availability impact gas generation rates and effective gas generation potentials? To what extent does room closure impact room pressurization and associated flow into and out of the disposal room? Will the disposal-room gas pressures become sufficiently high to propagate existing fractures in the marker beds or initiate new fractures? How would the expected disposal-room response be altered if waste or backfill or both were altered?

The technical approach to understanding the migration and dissipation of gases in the Salado and the effect of gas getters in the backfill materials is to develop a rigorous set of models describing gas generation and actinide solubility within the disposal room, two-phase fluid flow (gas and brine) in the Salado, creep closure and consolidation of the disposal room and backfill, fracturing behavior of the interbeds within the Salado, and the physical coupling among the several processes and model elements. A series of laboratory experiments will establish the necessary parameter set for each component of the overall model, such as creep properties of the salt; two-phase-flow properties of the salt, anhydrite marker beds, backfill, and waste; and gas generation and actinide solubility in brine as a function of the waste materials placed in the disposal room. The studies described in this Section (5.3.1) support this technical approach.

5.2.1.1 Properties of Disposal-Room Backfill

Description

The concept for waste emplacement in the WIPP facility assumes that access-ways, drifts, and waste-filled rooms will be backfilled to reduce the time required for closure and to reduce the long-term permeability. Backfill response is of special interest for those backfills containing substantial gas-gettering additives. Past backfill studies in the laboratory have concentrated on the creep-consolidation and permeability of pure crushed salt, and mixtures of crushed salt and bentonite. The effects of bentonite swelling in response to brine inflow were included as part of these studies. Sufficient information has been collected to conclude that these studies are largely complete, and are adequate, so long as no further additives are added as part of the backfill material. The mechanical response and permeability of other backfill materials, proposed by the Engineered Alternatives Task Force (EATF) (DOE, 1991b), such as cement or salt-grout mixtures, may eventually be examined.

The objective would be to evaluate if material properties for such materials, as described in the literature, are adequate for WIPP purposes.

Justification

Experimental information on the backfill is used in performance-assessment calculations of transport of fluids through and gas storage within the disposal room. The results are essential to the construction of consolidation models (Section 5.2.1.3), which in turn are used for room closure analyses (Section 5.2.1.5) that provide computationally efficient models for performance assessment.

5.2.1.2 Mechanical and Permeability Properties of Waste

Description

Laboratory studies of the consolidation and permeability of simulated unmodified or untreated wastes contained in drums and boxes have provided numerical estimates of the mechanical backstress occurring from collapse of waste-filled containers, as well as estimates of the time and state of waste compaction at which this backstress might begin to retard room closure. Also, these studies help define the final or maximum state of compaction and permeability for the wastes, after room compaction or closure. Work has been completed examining the consolidation and permeability characteristics of simulated unprocessed wastes (combustibles, metallic wastes, and sludges). Sufficient information has been collected to conclude that these studies are largely complete, and are adequate for unprocessed wastes. The mechanical response and permeability of some modified waste forms, such as those proposed by the EATF, may eventually need to be examined, however.

Justification

Collapse models for waste filled containers are needed in the disposal-room model to describe the backstress the waste exerts on the backfill and walls of the disposal room as closure occurs. A description of the process of compaction of the waste within the disposal room, the porosity available for brine to occupy, and the permeability of the waste in its compacted condition are needed to develop a model of the process (see Section 5.2.1.4) for performance assessment.

5.2.1.3 Mechanical Model of Disposal-Room Backfill

Description

Laboratory studies of the creep consolidation and permeability of pure-salt and salt/bentonite backfills have been completed (Section 5.2.1.1). The results of these studies have been used to create numerical constitutive models of these backfill materials for use in complex finite-element disposal-room models (Section 5.2.1.5). The constitutive models for salt and salt/bentonite backfills are considered sufficient for performance assessment. The models are, therefore, considered complete, unless work in the backfill-mix laboratory studies alter these models to an extent beyond adjustment of a single model parameter, or unless consideration of backfill alternatives (see Section 5.2.1.6) indicates a need for further model development.

Justification

The current concept of waste emplacement in the WIPP is based on the assumption that access-ways, drifts, and waste-filled disposal rooms will be backfilled with materials tailored to improve the closure process (i.e., tailored to reduce time required for closure and improve long-term impermeability). As

a result, constitutive models of the backfill must be developed, based on experimental data (Section 5.2.1.1), that can be incorporated in the disposal room model (Section 5.2.1.5) to study the behavior of the backfill and to correctly simulate the mechanical response to allow investigations of total room system behavior (i.e., room closure, consolidation, gas generation, brine inflow, etc.). The results of the room system's response are then needed for performance assessment to aid in construction of appropriate performance-assessment models and to provide values of parameters such as room porosity and permeability for the models.

5.2.1.4 Model of Waste Mechanical Properties

Description

Waste in the disposal room can create mechanical backstress against creep closure of the room. These backstresses can slow or prevent further closure, and therefore influence both fluid-storage and fluid-transport mechanisms. Laboratory studies of the consolidation of unprocessed wastes in drums have provided experimental data from which constitutive models of unprocessed wastes have been developed. Therefore, the mechanical models for unprocessed wastes are considered to be complete. No further model development is needed, unless additional information is required for performance assessment, or proposed modifications (see Section 5.2.1.6 on Engineered Alternatives) of the waste indicate that additional work is needed.

Justification

Waste collapse models are needed in the disposal room model to describe the backstress the waste exerts on the backfill and walls of the disposal room as closure occurs (Section 5.2.1.5). Development of the backstress helps determine the final state of compaction of the waste within the disposal room and, therefore, the amount of porosity that exists for brine to occupy. In addition, the extent of compaction of the waste helps determine the permeability of the waste, which influences radionuclide transport mechanisms.

5.2.1.5 Disposal-Room Model and Data Base

Description

Mechanical consolidation of the waste and backfill in the disposal room, caused by the creep closure of the room, is the primary factor that determines the time-dependent permeability and porosity within the disposal room. These closure and consolidation processes are coupled with gas generation and brine-phase and gas-phase transport of both radionuclides and volatile components within the room and in the surrounding formation. The disposal-room model is used to compute time-dependent porosities (and hence permeabilities) of the waste and backfill within the disposal rooms. Disposal-room modeling is also concerned with Salado fluid flow and fracture-enhanced permeability of the Salado marker beds near the planned repository, because gas leakage through these interbeds might influence both gas pressurization and fluid flow within the repository and fluid-phase transport of contaminants outside the repository.

These models must adequately simulate the creep of the near-field portions of the Salado that causes room closure; the responses of both backfill and wastes to such closure; the impacts of the resulting room pressurization on brine inflow and outflow; and the impacts of all of these processes on gas generation rates and effective potentials. Because all of these processes are expected to be tightly coupled, the analysis models must describe the interaction of the processes to an acceptable level of detail, at the geometric scale of the disposal room. Thus, the disposal-room model will describe the

phenomenological behavior of the disposal room to a greater level of detail than do the models expected to be used directly in performance assessment, and is expected to be more descriptive of the mechanisms involved in room-scale responses to waste emplacement. This model will be used to evaluate room-scale responses to all waste forms that may be emplaced in the WIPP, including engineered alternative waste forms. This detailed disposal-room model will be used to benchmark the computationally efficient representation of disposal room behavior that must be incorporated into the performance assessment.

Justification

The disposal room model supplies porosities (and permeabilities) that can then be used by performance assessment. Furthermore, the disposal room model studies in much greater detail the phenomenological behavior of the disposal room than do the models used in performance assessment and, therefore, is expected to be more descriptive in predicting room behavior. In addition to providing basic closure information, the disposal room modeling also serves as an indicator of which phenomena should be modeled in the performance assessment and which phenomena do not significantly impact performance.

5.2.1.6 Model of Engineered Alternatives

Description

The engineered alternatives task force has identified several different combinations of processed waste, packaging, and backfills that could be used in the WIPP (DOE, 1991b). Evaluations of these combinations in terms of disposal room response would require the development of new constitutive models for the backfill and waste combinations and would require numerical finite-element analysis. This effort also serves to verify codes used in the disposal room model.

Justification

The disposal room response after the sealing of the panels can be strongly influenced by the waste form in terms of both the backstress the waste forms produce and the amount of gas generated in the room, which also produces a backstress. These behaviors also impact the hydrological properties of the waste and, hence, the transport of radionuclides (Section 5.6.2.5). The iterative calculations for performance assessment require the development of efficient tools and staff capabilities.

5.2.1.7 Tests of Simulated Disposal Rooms (Rooms T and J)

Description

The simulated CH TRU tests, emplaced in 1986, comprise 120 drums in a crushed salt backfill room, and 120 drums in a salt/bentonite clay backfill room. These two rooms within WIPP Room T (see Figure 1-4) are constrained on three sides but subject to wall closure forces on the fourth side. Data are remotely recorded for room closure and stress/strain on drums, but analyses of backfill consolidation, degree of brine saturation and drum deformation will only be available once the room is reopened.

The simulated RH TRU tests, also emplaced in 1986, comprise eight canisters emplaced in boreholes in the walls of Room T. Some heated canisters are surrounded by backfill while others are not. Heat levels vary to cover expected thermal output to upper bound (300 watts/canister) levels. In addition to remotely recorded data, recovery will be necessary to deduce brine-seepage and backfill effects.

The material interface interaction tests in Room J have been completed and await final reporting. Candidate waste package backfill and getter materials, associated near-field samples, and simulated waste forms were analyzed. Corrosion and metallurgical laboratory analyses of waste containers were performed. Geochemical stability and chemical plus physical properties and alterations of associated metallic equipment, instruments, protective coatings, backfill, and getter materials were analyzed. A small amount of applied laboratory research is also necessary to support test termination and final data interpretations.

Justification

These simulated CH and RH TRU tests provide the only direct in-situ experimental information on the mechanical stresses on canisters due to salt creep; on CH TRU drum disposal configuration; the degree of backfill consolidation, the amount of brine wicking into backfill, and subsequent corrosion; and on the deformation of drums in the time period of WIPP operations.

5.2.1.8 Feasibility Analysis for Room-Scale Test

Description

The feasibility analysis considered here pertains to commitments made by DOE in the April 1990 *WIPP Test Phase Plan* (DOE, 1990d) to conduct a feasibility study for long-term monitoring of a waste-filled room. The feasibility analysis will identify state-of-the-art systems needed to conduct long-term monitoring in the WIPP underground environment. Instruments capable of functioning unattended for prolonged periods will be evaluated along with any modifications, additions, or technological advances that may be necessary to accomplish this objective. The feasibility study will determine the extent to which monitoring data or quantitative measurements from such tests may be useful for the final performance assessment for the disposal decision, or for confirmation of assumptions made for the performance-assessment calculations to demonstrate continued compliance throughout the disposal phase.

Justification

This study is intended to investigate whether it is feasible, from a technical perspective, to conduct room-scale monitoring in the WIPP environment. The confirmation of assumptions made for the final performance assessment may necessitate such monitoring of a disposal room during the disposal and decommissioning phases.

5.2.2 Shaft, Drift, and Borehole Seals Performance Activity

Seals and plugs are designed to prevent shafts, drifts, panel entryways, and boreholes from becoming preferential pathways for escape of regulated waste constituents. Short-term shaft seals and borehole plugs are also necessary to prevent intrusion of ground water into consolidating crushed salt seal components and disposal rooms from water-bearing zones in the Rustler Formation until long-term seals take over that function. Short-term drift and panel entryway seals are necessary for operational safety during the disposal phase and to assist consolidation of salt sealing components by confining the components.

The objective of the set of studies comprising this activity is to provide models of the performance of sealing system components and values for the parameters needed for those models for incorporation into the performance assessment. The models and recommended parameters will be based on combinations of laboratory measurements, field measurements, and detailed numerical analyses.

Laboratory measurements of the properties of seal materials will establish the anticipated range of values at the time of emplacement and after interactions with the WIPP environment. Field measurements of the initial performance of seal components will demonstrate the behavior of selected components in the WIPP environment. Detailed numerical analyses of component performance will evaluate both the structural integrity and flow resistance of components; these analyses will evaluate the more empirical models used directly in the performance assessments to assure that the range of behavior predicted by the detailed models is captured by the performance-assessment models. These evaluations will also seek to confirm the conceptual models used to simulate the behavior of the seals; particular emphasis is upon evaluations of the models of salt-seal consolidation, characterizations of the disturbed rock zone and its subsequent healing, and potential short-term (< 100 years) flow past concrete, clay, and bitumen components of the seals.

Research, development, modeling, and design studies focus on answering the following questions. How long will it take for long-term seal materials made of salt to consolidate into effective long-term seal components? What is the flow resistance of individual seal components and seals as a function of time for operational and long-term regulatory periods? What is the overall performance of the sealing system for limiting flow as a function of time for the three periods of institutional control? Will the clay, concrete, and grout short-term seal component materials be sufficiently stable in WIPP host rocks and brines to perform adequately during their required lifetime? What are the permeabilities, porosities, and other materials properties as functions of time? What materials formulations resist geochemical degradation? Are there interactions that will occur between seal materials and hazardous constituents that may decrease seal performance? What evidence is there that the seals can be designed and built to perform as predicted?

The technical approach to predicting sealing effectiveness as a function of time is to conduct laboratory experiments for development and characterization of seal materials; conduct experiments and in-situ tests to characterize the disturbed rock zone and assess efficacy of small-scale seals; generate seal models based on materials properties and seal designs; and demonstrate emplacement technology, as well as initial performance, that meets design requirements. A detailed conceptual design and in-situ demonstrations of seal emplacement technology and of initial performance that meets design criteria are necessary to confirm predictions of seal performance.

5.2.2.1 Development of Materials for Short-Term Seals

Description

Seal and plug materials with the required mechanical and fluid flow properties and geochemical stability to contain and protect crushed-salt seal material for up to 100 years are being developed and evaluated. These are called short-term seal materials. Current design concepts include concrete, grout, and swelling clay components (bitumen and other materials may be considered in future evaluations). These materials are also being characterized to provide data for design-related calculations and analyses. Concrete formulations are being developed by laboratory studies that address chemical reactions in WIPP-specific environments and design-related properties such as compressive strength and thermomechanical curing behavior. Laboratory tests will produce geochemical stability data for performance modeling and will guide the formulation of concretes. Laboratory tests will also produce data on the characterization of thermal and physical properties. Similar studies are being carried out for the development and characterization of grout materials for disturbed rock zone sealing. Swelling clay material will be tested to evaluate the geochemical stability of the material and to provide data for tailoring the initial density of swelling clay components to achieve desired swelling pressures.

Preliminary specifications for short-term seal materials have been given in the initial reference sealing system design. Concrete formulations are being developed further for ongoing work on sealing system design criteria and the development of a detailed conceptual design. Grout formulations are being developed, tested, and evaluated with laboratory tests. Field tests have been planned for grout development.

Justification

This study addresses information needed about the entire WIPP sealing system for performance assessment. This study is designed to provide required information for studies in seal design and system modeling (Section 5.2.3.1), seal component modeling (Section 5.2.2.4), small-scale seal performance tests (Section 5.2.2.6), large-scale seal tests (Section 5.2.2.7), and borehole plugging tests (Section 5.2.2.8). These are parallel studies with iterative exchange of information. A significant portion of this study must be performed prior to the conduct the field studies of large-scale seals described in Section 5.2.2.7.

5.2.2.2 Development of Materials for Crushed-Salt Seals

Description

Because reconsolidated crushed salt is the key long-term seal material in current seal designs, accurate constitutive models, permeability relationships, and mechanistic understanding of crushed salt consolidation are being developed. Effects of filling pores within the crushed salt with brine will be used to quantify the required performance of upper-shaft seals that control brine inflow from the Rustler Formation. Laboratory tests are being used to quantify effects of brine saturation (brine-filled pores), hydrostatic stress, shear stress, and particle-size distribution on consolidation rates and on the constitutive model. Permeabilities of the test samples are being measured to relate permeability to consolidated density and other consolidation parameters. Since field demonstrations of the performance (consolidation) of crushed salt are not feasible under actual repository conditions, micromechanical models are being developed to support the predictive capability of the constitutive model derived from laboratory data.

Laboratory studies have confirmed the rapid reconsolidation of moistened crushed salt under hydrostatic pressure. A constitutive model for crushed salt derived from the laboratory data (relating permeability to density of reconsolidated salt) and creep closure calculations were used for shaft seal analyses. These analyses show that consolidation to 95% of intact-salt density should be complete well within 100 years, and that the permeability of the reconsolidated salt at that density will be within an order-of-magnitude of the permeability of intact host-rock salt. A mechanistic model for the consolidation of dry crushed salt has been developed to provide a foundation for a mechanistic model of the consolidation of wet crushed salt.

Justification

The focus of this study is to gather data concerning the sealing subsystem for the lower shaft sections. This study is designed to provide information for studies in seal design and system modeling (Section 5.2.3.1), seal component modeling (Section 5.2.2.4), and borehole plugging tests (Section 5.2.2.8). These studies are performed synchronously with iterative exchange of information.

5.2.2.3 Data Base for Seals Materials

Description

Data on seal materials and processing effects must be compiled, documented, and evaluated. This documentation will help determine the range of values for performance assessments for material properties of the sealing system. The materials to be included in the WIPP data base are concrete (and its numerous constituents), crushed salt, bentonite, bitumen, and other potential seal materials such as cementitious or chemical grouts. The data base must be assessed, appropriate methods for evaluating the data must be documented, and the basis specified for the recommended parameters. External, independent peer reviews of the data and the process must be completed.

Justification

The seal database should document and provide an adequate pedigree for all seals data collected by the WIPP Project.

5.2.2.4 Model of Seals Components

Description

Models and codes to calculate and analyze the structural and flow performance of seal and plug components are needed to assess designs, develop design criteria, plan tests, and design experiments. Models of seal components will also be integrated into system models for performance assessment. The models will include host rock responses and the evolution of the disturbed rock zone. Processes such as brine inflow, creep closure, crushed salt consolidation, and disturbed-rock-zone formation will be linked and coupled when necessary. The calculated thermomechanical behavior of concrete seal components during curing will also be used to assess the integrity and mechanical stability of large, poured-concrete structures.

Modeling and calculations (based on current assumptions) have already been used to show adequate consolidation of crushed-salt seal components in shafts and drifts. Seal-component models have also been used to derive performance requirements for upper shaft seals.

Justification

The seal-component model and evaluation study are designed to provide information needed for the assessment of total system performance. This study is designed to provide information for seal design and system modeling (Section 5.2.3.1), small-scale seal performance tests (Section 5.2.2.6), large-scale seal tests (Section 5.2.2.7), and borehole plugging tests (Section 5.2.2.8). These studies are performed synchronously with iterative exchange of information. This modeling of the real components uses the computational models developed in rock mechanics and hydrology studies.

5.2.2.5 Sealing System Integration

Description

A number of diverse studies, including modeling and numerical analyses of complex sealing systems, laboratory studies, and in-situ tests, must be integrated to complete a detailed conceptual design of the WIPP sealing system and to provide information for the performance assessment. Sealing studies must be integrated with numerous site- and operation-related studies of the location of seals, materials

used in the vicinity of seal locations, underground support systems, locations/logistics for in-situ tests, and the size of underground openings where seals will be emplaced. Operational and regulatory compliance requirements for panel seals will be identified and integrated into the seals design program. Design criteria will be evaluated in the light of overall repository system performance evaluations. The performance assessment will generate data on performance requirements, which in turn will be used to evaluate conceptual design. Overall management of the sealing R&D program and interface with other programs (performance assessment, operations, source-term, etc.) will be done as part of this integration process.

Justification

This study integrates overall performance-assessment information needs with the information needs of the entire WIPP sealing system. This study is designed to provide required information to all studies in the sealing system program. It is performed in parallel with all other studies and involves iterative exchanges of information with site operations, waste characterization, and performance-assessment groups.

5.2.2.6 Small-Scale Tests of Seal Performance

Description

Data on thermal, structural, and fluid-flow performance of emplaced seal materials are needed for the development of appropriate seal materials and emplacement techniques. These data will also be used to help validate the performance assessment and to design the sealing system. Specifically, small-scale evaluation of approaches have been made for attaining satisfactory initial densities, establishing attainable permeabilities, and demonstrating construction method. Concrete, crushed-salt, and bentonite seal materials were emplaced in horizontal and vertical boreholes with diameters in the range of 0.1 m to 1 m. The first of these small-scale seals was emplaced in 1985; monitoring of their performance will continue. Small-scale tests will also be carried out to characterize the disturbed rock zone around excavations (primarily in MB 139) and to develop and evaluate grouting techniques for the disturbed rock zone. The fluid flow characteristics of the disturbed rock zone will be measured before and after seals have been grouted. Boreholes drilled through concrete retaining structures (structures used to resist grout emplacement pressures) will be utilized for emplacing grout and measuring gas flow in the grouted disturbed rock zone.

This study has provided thermal, structural, and fluid-flow data and has demonstrated emplacement techniques for concrete, crushed salt, and bentonite seal materials on a small scale. Retesting of small-scale seals that have been emplaced for several years is also planned.

Justification

This study is designed to provide data on designs and ranges of anticipated material properties specified for the seal materials simulated in performance assessments of the WIPP sealing system. This study is designed to provide required information to studies of seal design and system modeling (Section 5.2.3.1), seal component modeling (Section 5.2.2.4), large-scale seal tests (Section 5.2.2.7), and borehole plugging tests (Section 5.2.2.8). These are parallel studies with iterative exchange of information. A significant portion of this study has been completed and the results provide significant information to the design of the large-scale seal tests described in Section 5.2.2.7.

5.2.2.7 Large-Scale Testing of Seals

Description

Large-scale testing is needed to evaluate sealing concepts for the shaft and panel seals. The expected performance of shaft and waste panel seals will be based in large part upon laboratory and field data, small-scale in-situ tests, and modeling. However, small-scale tests do not fully simulate the development of the disturbed zone around larger excavations and do not fully demonstrate the required emplacement techniques. Previous seal evaluations indicate that the seal/rock interface and rock adjacent to the seals are the most likely hydrologic flow paths. Additionally, stresses or deformation caused by the excavation, seal emplacement, or rock creep may affect both seal and rock performance.

The reference seal system design calls for seals to be composed of concrete components, quarried salt, salt/bentonite mixtures, or pressed salt blocks. This long-term seal should provide a sealing capability comparable to the intact salt formation itself, in less than 100 years after emplacement of the multi-component seal system, by the process of reconsolidation of the crushed salt component of the seal system. The seal design provides for removal of heavily fractured rock to minimize the potential for seal bypass. The multiple component design also provides some redundancy. Panel seal components include concrete to confine crushed-salt seal components, reverse formation disturbance by causing stress build-up, and provide a short-term flow barrier.

Large-scale seal tests will be designed to examine salt, bentonite, concrete and other seal components that will be emplaced underground. Specific test geometries and emplacement methods have not yet been determined. As currently planned, the initial test will involve an instrumented, large concrete pour, designed to evaluate flow around or through this barrier; flow (leakage) remediation by grouting; and validation of design assumptions related to concrete curing, quality control, heat of hydration, and cracking. Full-scale panel seal and shaft seal components are being considered, as needed, for demonstration in the second and third phases of these tests. Detailed planning of these tests will include design, construction, testing, performance evaluation, and quality control specifications.

Justification

Validation of the seal designs and evaluation of the performance of large-scale seals will help establish confidence in the sealing system. This study is designed to provide for the performance assessment information about the WIPP drift and panel sealing subsystem, the upper shaft sealing subsystem, and the lower shaft sealing subsystem. This study requires specific information from seal laboratory studies and seal design and modeling studies and general information from virtually all sealing studies. The field studies elements are interactive.

5.2.2.8 Borehole Plugging Tests

Description

To prevent dissolution of the WIPP host-rock salt that serves to isolate TRU mixed waste and to effectively control fluid flow in WIPP host rocks, selected surface-based boreholes will be identified for conducting design and emplacement-technique development tests. Criteria for selecting which boreholes will be plugged will reflect performance-assessment factors such as the proximity to the WIPP repository and the depth of the borehole. Borehole plugging systems will be designed. Plugging concepts address the Salado and Castile Formations as well as any other formations having

significant potential to yield ground water. Evaluations of plugging material interactions and compatibilities with other materials surrounding the borehole will be addressed in laboratory studies and modeling work. Design criteria and detailed conceptual designs for borehole plugging will be integrated with the design criteria for the WIPP sealing system and with the development of models and parameters for performance assessment.

Materials used for shafts or drift seals are in many instances applicable to borehole plugs. Some borehole plugging tests have been completed at WIPP. Further in-situ testing of plug emplacements in boreholes will be initiated, if necessary, after further materials development and design definition have been completed.

Justification

Borehole plugs will be designed to preclude transport of significant quantities of radioactive materials from the repository. The designs depend on the physical separation that will exist between the boreholes and the repository openings. This study requires information from crushed salt seal material development studies (Section 5.2.2.6) and short-term seal materials development studies (Section 5.2.2.1). This study is designed to provide information to studies in seal component modeling (Section 5.2.2.4) and seal design and system modeling (Section 5.2.3.1).

5.2.3 Shaft, Drift, and Borehole Seals Designs Activity

The seal-design program for the planned WIPP repository is focused upon addressing scientific and engineering questions related to feasible ways of emplacing high-quality, effective seals that will limit gas or liquid flow through shafts, drifts, and boreholes. Since the seals cannot generally be tested after they are installed in the repository, it is important to evaluate and demonstrate the quality control necessary during construction of the seals to assure the required performance of the individual seal components.

The objective of the design work related to the sealing program is to provide validated, detailed designs of the seal components. Detailed designs are required to provide assurance that the proposed seal components can be feasibly emplaced with sufficient quality control to ensure the needed performance. Demonstrations of the feasibility of constructing selected components are planned as part of the validation efforts.

Design-related questions include the following. What sizes, shapes and numbers of components are needed? Where should the seal components be located? What materials should be used? What methods are preferred for installing the seals? What construction approaches should be taken to limit costs while enhancing seal performance?

The technical approach for this design effort is iterative. Initial concepts and general criteria were developed and evaluated; an initial reference design was then created for each component. Functions of the individual components are being identified and performance criteria are being developed. Detailed conceptual designs will be developed for each component; construction drawings will be prepared for the components of the large-scale seal tests. Design validation studies will focus on documenting similar construction, on structural analyses of the expected conditions, and on the site-specific demonstrations planned as part of the large-scale testing at WIPP.

5.2.3.1 Seal Design and System Model

Description

A detailed conceptual design for the WIPP sealing system will provide a basis for preparing a construction design and will also provide input for the development of a sealing system model for performance assessment. Initial work to produce a detailed conceptual design will include numerical analyses, cost analyses, feasibility design evaluations, design criteria preparation, and other studies. Also, designs for the large-scale seal tests (Section 5.2.2.7) will be created. An assessment of the seal system performance will generate information for the total-system-performance-assessment calculations. A preliminary seal design evaluation and an initial reference seal system design will provide a basis for the subsequent detailed conceptual design work and initial planning of in-situ tests. Work is underway to generate design criteria for and feasibility analyses of the sealing system.

Justification

The process of designing seals to meet performance requirements is complex. The compacted-salt components within the seal system will require tens of years to compact to a state approaching that of the undisturbed salt with the low permeability appropriate for long-term seal performance. During this time, short-term seal components will be required to provide the low-permeability seal necessary to retard gas flow out of the repository and water flow into the consolidating salt of the long-term seal. The design process will include determining the ranges of anticipated material behavior, based on laboratory and in situ testing and will establish detailed specifications for the major processes (such as concrete placement, salt compaction, and bentonite usage) that could impact performance. Major structural and flow-modeling efforts are required to simulate the behavior of the crushed salt and the performance of the short-term components. Performance requirements for the various components will be established using these models and the performance of individual components will be predicted. These models will be used in the design process and some will be recommended for use in the total-system performance assessment. The models will be validated with both laboratory and in situ data to provide assurance that the behavior of the seal components is accurately simulated. Design validation work will focus on results of in situ seal tests, documented industrial experience with similar materials, and flow and structural analysis of anticipated performance.

This study is designed to provide the designs and models that will be used as the basis for all performance assessments that consider the WIPP sealing system. This study provides required input to small-scale seal performance tests (Section 5.2.2.6), large-scale seal tests (Section 5.2.2.7), and borehole plugging tests (Section 5.2.2.8). These are parallel studies with iterative exchange of input.

5.2.4 Disturbed Rock Zone Permeability Activity

A seal includes emplaced grouts in the disturbed rock zone of surrounding interbeds and hard rocks and, for seals in salt, predictable salt-fracture healing in the surrounding disturbed rock zone. Grouting is envisioned for rock surrounding upper shaft seals in the Rustler Formation and for interbeds surrounding seals in the Salado Formation. Salt-fracture healing is critical to the performance of long-term shaft seals.

The objectives of evaluating the disturbed rock zone are to establish the extent of disturbance near WIPP underground openings, to assess healing mechanisms, to determine the effectiveness of grouting in the disturbed rock zone, and to develop models to predict the observed behavior of the disturbed rock zone. Models of the disturbed rock zone will be used to evaluate the potential for flow past seal components and to aid in assessing the degree of grouting that may be needed near seals.

Research and modeling of salt-fracture healing will focus on answering the following questions. Will the disturbed rock zone in host-rock salt surrounding seals heal with sufficiently low permeability to satisfy seal performance requirements? How long will healing take? What will be the permeability of the disturbed rock zone as a function of time?

Research, development, testing, and modeling of hard rock and interbed disturbed-rock zone properties focus on answering the following questions. How much of the disturbed-rock zone must be grouted? Can grouts and grouting technology be developed to adequately grout the disturbed-rock zone? What will be the permeability of the grouted zone as a function of time (i.e., will the grouted zone adequately resist fluid flow)? The technical approach to resolving these questions is defined and supported by the studies described in this Section (5.2.4).

5.2.4.1 Study of Material and Fracture Properties

Description

This work consists of laboratory tests to define the creep parameters of the stress rupture mechanism that controls most of the fracture phenomena observed at the WIPP. The intent is to determine experimentally the strain at which the onset of tertiary creep occurs as a function of confining pressure and stress path (Lode angle). Results will be interpreted using the decrease in ultrasonic wave speed as a measure of accumulation of damage, a measure that will be utilized in the healing kinetics study as well as the fracture properties study. In addition, the total strain to failure will be determined using compression and extension triaxial tests to identify the necessary conditions and stress paths. These parameters will be incorporated into the constitutive models of fracture currently under development.

The fracture parameters will be obtained primarily from the compression load path tests, followed by the extension load path tests. These tests will be concentrated at just two confining pressure levels at room temperature. The intent is to complete between 12 and 16 tests. The need for follow-on tests will depend upon the results of the initial tests.

Justification

Fracturing of the salt surrounding rooms, drifts and shafts in the WIPP underground workings results from the creep-closure process. Such fracturing can impact the isolation performance in at least two ways. First, the fractures that propogate out into the surrounding rock (salt) can influence the quantity and rate of brine flow from the rock into disposal rooms, and thus impact the disposal room performance (see Section 5.2.1, Disposal Room Performance Activity). Second, the fractures can also influence the performance of the seals by providing paths for leakage around an emplaced seal. Most performance evaluations depend strongly upon the permeability of the seal system, including the permeability of the salt in the disturbed zone adjacent to the seal. Because the salt deforms with time, it can fracture, which increases the permeability of the system. Through the detailed study of this fracture process and the quantification of the creep damage accumulation, this study can predict seal performance during the phase in which damage continues to increase in the salt around the seal. Finally, the state of maximum fracture around openings forms the initial condition for rehealing of fractures during the compaction stages of room closure and during the closing (healing) of fractures around emplaced seals.

5.2.4.2 Disturbed-Rock-Zone Mechanisms

Description

The study of disturbed zone mechanisms is focused on the generation of cracks in an in-situ body of salt as it undergoes deformation. One method of detecting the formation of microcracks is by observing decreases in ultrasonic wave speed occurring with increases in crack-generating deformation. Measurements are made of the ultrasonic wave speed as a function of the amount of specimen creep strain (deformation) for various confining pressures. A qualitative evaluation of the microstructure is made to define the degree of cracking. In addition, specimen gas permeabilities obtained concurrently with specimen deformation are used to evaluate the proportion of connected cracks.

Preliminary studies of the response of the ultrasonic wave speed correlating to deformation have been made; however, the earlier unconfined specimens were too highly deformed for determining the effect of moisture on creep. This study is focused more on smaller deformations in the presence of confining pressure.

Justification

Understanding the mechanism of crack formation is important to the performance of seals and seal systems. In the disturbed rock zone around the seals, deformation-induced cracks can lead to increases in permeability and potential degradation of important seal characteristics. Deformation, in the absence of crack formation, is not detrimental, nor is the formation of isolated cracks. The problem occurs when the cracks connect to form continuous paths. It is important to know how much strain and what conditions of pressure cause a change in permeability.

5.2.4.3 Kinetics of Fracture Healing in Salt

Description

Quantification of the salt degradation and healing processes involves a study of the amount of fracture that develops as a function of strain under a given confining pressure, and of the time-and pressure-dependence of fracture healing. This study consists of parallel efforts. In the first effort, measurement of the strain-associated damage is dependent on continued development of an ultrasonic detection system and technique for quantifying the extent of fracture. With the damage techniques already established, the second major effort is the healing study, in which deformed specimens will be subjected to different pressures to determine the kinetics of the healing process.

Currently, the ultrasonic detection system, except for minor improvements, is adequate; development of the fracture quantity (i.e., fracture density) with strain at a given confining pressure is considered to be understood; and preliminary studies of the healing process are completed.

The current effort involves establishing the relationship between the damage state (strain) and the kinetics of salt healing under pressure.

Justification

Integrity of plugs and seals emplaced in the repository is dependent on the integrity of the salt around the seal (i.e., in the disturbed rock zone). Loss of integrity through increased permeability of this salt could defeat the seal system. Excavation compromises the integrity of the surrounding salt by

increasing permeability and fracturing. Once the seal is emplaced and begins to take up stress from the creep of salt around the seal, the stress condition in the surrounding salt changes the pressure — the spherical stress component increases while the shear (deviatoric) stress component decreases toward a hydrostatic stress state. Earlier laboratory evidence indicates that existing fractures will heal under pressure as the pressure develops in the salt around the seal; it is important to quantify this healing process in detail.

5.2.4.4 Mechanical Model of Excavation Effects in the Disturbed Rock Zone

Description

This study requires development of a model that can link excavation effects in the disturbed rock zone to the changes in salt and anhydrite permeability. The model, in its initial phases of development, uses quasi-static deformation and laboratory properties to give a preliminary prediction of the permeability of the disturbed rock zone. The data generated by the model of the disturbed rock zone must be checked against field data, and further refinements must be made to the model to assure its accuracy. Currently, the preliminary quasi-static model has been developed. The data developed by this model will be verified against the gas and brine permeability data collected from the repository horizon.

Justification

The disturbed rock zone, the region in which mechanical and hydrologic properties have changed in response to excavation of the WIPP, needs to be characterized and defined. This description is a prime consideration in such key WIPP issues as containment of VOCs and transuranics during the operations phase, long-term repository sealing, waste-generated gas storage and dissipation, human intrusion scenarios, and excavation response and stability. In particular, design of the drift/panel seals and the shaft seals requires this description. Performance assessment of the repository system requires simulating the behavior of this zone. Understanding the disturbed rock zone will also enhance underground safety and the efficiency of mining operations.

5.2.4.5 Characterization of the Disturbed Rock Zone

Description

This study involves in-situ measurements of gas and brine flow in the immediate vicinity of excavations (the near field). Two types of tests are included. The small-scale mine-by experiment monitored changes in brine and gas permeability as a result of nearby excavation. The second type of test measures gas flow within disturbed rock zones throughout the WIPP underground. The intent is to complete measurements of gas permeability throughout the WIPP using existing drill holes. Several locations will be retested approximately four years after their most recent testing to evaluate the progression of the disturbance with time.

Justification

This study will contribute to the data base for the disturbed rock zone and is directly applicable to repository seal design. Significant issues addressed include the relationship between gas and brine permeabilities in the zone (i.e., whether gas at low pressures can displace pore brine and whether the zone has a uniform pore structure or appreciable fractures). These data are also relevant to other hydrologic investigations, such as permeability measurements in the Salado, Room Q permeability and brine inflow, small-scale brine inflow, and threshold pressure testing/two-phase properties.

5.2.4.6 Geophysics of the Disposal System

Description

Variations in the geophysical character of the WIPP disposal system, such as seismic velocity and electrical resistivity, are being used to monitor the development of fractures, the changes in porosity and/or permeability around an excavation, and the far-field hydrologic and mechanical properties. Geophysical methods are also being used to investigate excavation-induced phenomena (e.g., slabbing) from within the drifts and shafts. In upcoming studies, the effects of the shafts and the shaft seals on the near-surface hydrologic system will be monitored by surface geophysical methods.

This study is designed to provide an areal survey of resistivities and seismic velocities to delineate variations in permeability with depth and laterally within the WIPP underground. These data can direct further permeability testing. Data on the nature of the rock at seal locations will be obtained for seal design purposes. Changes in resistivity and seismic velocity around large-scale seals test sites will be monitored to give a performance measure for seal designers and performance assessment. Methods will be developed to identify areas in the back, floor, or rib (sidewalls) where separations and fractures are forming. These methods can also be used to help monitor the effectiveness of ground control methods.

Justification

This study is designed to provide relevant data to the sealing program regarding fractures and fracture pathways for the development of sealing strategies and to the performance-assessment program regarding fracture pathways for waste-generated gases and formation brines.

Because geophysical methods can delineate the disturbed rock zone at the proposed seal locations and determine changes in hydraulic and mechanical properties of the seal system with time, this study will contribute to seal design and modeling (see Section 5.2.3.1) and seal field studies (see Section 5.2.2). An additional benefit of using geophysical methods is lower cost, since such methods can characterize a greater number of areas in the WIPP underground more cost-effectively than drillhole-based methods.

This study will contribute to flow and transport modeling and hydrologic field studies (see Section 5.1.3), since electrical and seismic methods can determine lateral variations in water content and porosity (indirect permeability). Because preliminary electrical surveys indicate that large lateral variations in resistivity exist around the WIPP repository, this information will be essential in guiding hydrologic testing. Areas of high and low resistivities can be selected for hydrologic test holes underground to ensure a representative range of host rock properties. Electric and seismic methods can also delineate zones where the hydrology is dominated by fractures.

This study will contribute to the large-scale brine inflow experiments by (Section 5.1.3.14) measuring changes in density, void volume (porosity), and moisture content.

This study will contribute to mining operations by mapping the development of fractures and separations in the back and floor that can present a safety hazard and delay operations.

This study will contribute to the performance assessment by providing data and conceptual model refinement through the supporting studies and directly through hydrologic modeling, pathways modeling, and repository and shaft systems modeling (see Section 3.1.1.2).

5.2.4.7 Hydrofracture Studies of the Anhydrite Beds

Description

In-situ tests will measure the behavior of fractures in the anhydrite and the salt/anhydrite interface of MB 139. Data will be obtained for stress states, fluid pressures, and other conditions related to fracture propagation in MB 139 and in other anhydrite beds. Other anhydrite beds will serve as analogs for MB 139 in locations unaffected by the WIPP excavations.

Justification

Pressures resulting from gas generation by waste may be limited to values near lithostatic by the progressive opening of fracture volume in the anhydrite layer or at the salt/anhydrite interfaces, or both, in MB 139. A data base and model description are needed for this potential process that could provide a reservoir or flow path for gas.

5.2.5 Shaft, Drift, and Borehole Closure Activity

The closure evaluations will help validate the mechanical behavior of the salt. Laboratory studies and large-scale experiments at the WIPP investigate creep, fracturing, and subsequent healing of the salt. The mechanical models must be coupled with hydrologic flow models to assess coupled flow and deformation effects associated with creep closure of the disposal rooms. The models form the basis for evaluating the performance of structural support systems during the operational period, the short-term (< 100 years) behavior of seal components, and the long-term response of the salt near the disposal rooms or the shafts.

Two fundamental questions about shaft, drift, and borehole closure concern the mechanical response of the salt into which the planned repository is excavated. The answers describe the behavior of the disposal room and its contents, the disturbed rock zone, fractures, and seals. How quickly and completely do vertical and horizontal openings into the underground facility close? How do backfill and fluid pressures affect this closure?

These questions must be resolved before several necessary models can be developed. The technical approach is defined by the studies described in this Section (5.2.5).

5.2.5.1 Distribution Functions for Creep Parameters

Description

The focus of this effort is to quantify both the loading and excavation strains not described in the current data base and to make the data base adequate for determining creep distribution functions. The creep response will be defined in probabilistic terms. If the distribution functions are poorly defined, the 95% limits can be so wide as to give unacceptable closure times. Methods of tightening these limits will be investigated to determine the extent of additional testing or analysis. A minor testing study will be established to narrow the uncertainty in the distribution functions.

A complete set of preliminary distribution functions has been established for pure salt. Supplemental tests on pure, polyhalitic, and argillaceous salt will continue to provide data for these materials. A new set of distribution functions will be determined for pure salt and the set will be extended as permitted by the data to argillaceous and polyhalitic salts.

Justification

Because the time of room closure and the details of the structural response under the superimposed conditions of gas generation and room content compaction are fundamental to the performance assessment, the creep closure must be adequately described with distribution functions and significance levels. Reducing the uncertainty in the distribution functions will reduce uncertainties in the calculations of many aspects of repository performance.

5.2.5.2 Validation, Documentation, and QA for the Rock-Mechanics Data Base

Description

For more than 15 years, data have been taken on the thermal and mechanical properties of salt. Throughout this time, data have been published that clearly indicate the results of numerous types of tests completed under a wide range of loading conditions. These data and associated reports must be compiled to allow peer review groups to scrutinize the basis chosen for specifying the creep and fracture models of salt behavior and the associated parameters chosen for use in these models. The reference models for use in thermal and mechanical simulations of the behavior rock salt will be documented in this study.

Justification

The predictions of shaft seal effectiveness, waste porosity changes with room closure, and gas pressure effects on the salt are needed to predict rock mechanics. This study will seek to certify the appropriateness of the models and parameters used in such predictions.

5.2.5.3 Development of Salt Constitutive Model

Description

A mathematical description (constitutive model) of the structural behavior of salt is needed in order to predict rock mechanics. This model must include all significant aspects of salt response dictated by the specific modeling application. Room closures result from stress loading on the salt; however, the reestablishment of the stress and pressure fields around a plug in the late stages of room closure is based on the unloading response of the salt. This portion of the constitutive model must be evaluated to assure its correctness. Also, the constitutive model must be changed to incorporate fracture damage accumulation and pressure rehealing. A proper mathematical match between the existing constitutive model and the fracture model (Section 5.2.5.4) being developed must be ensured.

The unloading portion of the constitutive model, including the unloading parameters, has been reexamined. Representative cases are being selected for calculation. At least one such case of potential interest is the construction and testing of the instrumented plug component.

The intent is to incorporate the damage measure into the constitutive model and to develop verification calculations to add confidence in the correctness of the formulation.

Justification

Two structural mechanics issues that impinge on facility operations are repository performance assessment and seal design. Proper recovery functions for stress unloading situations are needed in current models, and fracture and bed separation models for the disturbed zone around underground

excavations and adjacent to seals must be developed. First, because room closure calculations to date have not taken into account unloading, the creep recovery function has temporarily been taken as a constant since inclusion of this function is critical to seal design. Second, fracture modeling, also critical to the design and analysis of seal systems, has received less attention than required because it is dependent on data generated by the established creep constitutive model. Fracture models must be linked to continuum deformation models to adequately predict both the closure process of disposal rooms and access ways and the performance of shaft and access seals and borehole plugs.

5.2.5.4 Development of Fracture Constitutive Model

Description

The fracture-model development study, while not as developed as the salt-creep modeling study, has a significant theoretical and observational data base to draw upon. Two possible major failure mechanisms for the WIPP are derived from the fracture mechanism map: the stress-rate-dependent quasi-static fracture mechanism and the stress-rupture mechanism. The Bodner-Partom model is being used, which describes the onset of tertiary creep and provides a damage parameter to accelerate the normal creep process. This model begins at the strain calculated by the Munson-Dawson continuum creep deformation model. Incorporation of the damage parameter permits not only the description of massive salt failure but also provides a method of modeling bed separation.

The Bodner-Partom model has been incorporated into the existing multimechanism creep model, using German triaxial fracture data to supply the necessary quasi-static failure parameters. The program will now concentrate on the stress-rupture mechanism based on the Bodner-Partom model. The form of the model must be descriptive of the known constant strain-accumulation-to-failure typical of stress-rupture as a function of confining pressure. At this time, it is also possible to include a generic damage removal (healing) function in the model.

Justification

To support the seal design and the performance-assessment predictions of seal structural response and integrity, development of fractures must be understood. The time-dependent damage accumulation and crack growth have associated with them potential increases in permeability. How much this permeability increases as a result of strain in the salt adjacent to a seal will govern the overall performance of the seal. With a correct seal design, increases in damage and permeability can be minimized and, as the seal takes up pressure, the damage in the salt may decrease and cracks may heal, thus decreasing the effective permeability of the system. Because of the extended period of seal performance, this study is essential to assure that seal characteristics are predicted and that three-dimensional effects from the finite seal length are not detrimental. The Bodner-Partom fracture constitutive model appears promising as a predictive tool.

5.2.5.5 Development of Numerical Code

Description

This study consists of a major development effort to accommodate discrete fracture propagation in a finite-element code. Once the conditions for the fracture have been attained, there is considerable difficulty in treating the discrete fracture problem: the stress singularity, conversion of volume strain energy to fracture surface energy, and increased resolution through submeshing all must be adequately solved for the propagation of a discrete crack.

As the result of preliminary investigations of the approach to discrete fracture modeling, it appears that "adaptive meshing" is the most practical method. This method uses fracture information determined from the constitutive model and the finite element calculation to obtain localization based on energy error criteria. This localization is the equivalent of a discrete fracture. Efforts are underway to develop an appropriate adaptive meshing method for use in numerical codes.

Justification

In general, one of the most difficult problems is determining the failure and fracture response of the repository. Such failures concern roof slabbing and pillar deterioration, as well as seal deterioration. The design of seals must assure that fracture of salt and seal materials is adequately predicted so that the intended seal attributes are maintained. The primary concern for seal design is the deterioration through failure of the end portions of the multiple component seal system. Because of the success in predicting the continuum strains through the salt deformation model, any fracture criterion based on strain-to-failure likely will be successful and technically sound.

5.2.5.6 Verification and Validation of Code

Description

There are two major tasks within this study: benchmarking codes (computational models) and validating codes through comparison of these codes with in-situ test results. Verification through established benchmarking methods of the new two- and three-dimensional codes, with advanced models and generalizations, will continue as necessary to produce acceptable codes for performance assessment and operational safety analysis. Validation of the codes against the data in the extensive WIPP in-situ test data base will continue.

Currently, four single-room (heated and unheated) in-situ test closures and two multiple-room complexes have been successfully predicted. However, minor discrepancies remain in the results, probably due to code meshing, physical boundary extents, and unintentional minor variations in the numerical input.

The intent is to proceed to the final iteration of the validation exercise. This process will focus on the assurance of the correct numerical conditions, as well as the standardization of the model inputs.

Justification

A continuing effort must be made to ensure that the numerical codes are in fact producing physically correct calculations, independent of the structural model involved or the details of the constitutive equations. Typically, WIPP structural codes are certified against simple analytic solutions and are verified by benchmarking them against well-defined boundary value problems. The validation of computer codes for processes that will occur over several decades is challenging. Adequate code validation is essential because it is necessary to adequately predict the long-term structural response of room closure and encapsulation of the waste, the possible room reinflation from gas generation, and the long-term response of repository seals to deformation-induced permeability and eventual healing. Validation of data predicting long-term response against data in the in-situ data base obtained from the measured test room deformations is the only way that these highly nonlinear predictions can be demonstrated to be "correct" and adequate for performance assessment. Adequate validation of the structural codes will increase confidence in the predictions and aid in reducing the uncertainties associated with long-term structural predictions.

5.2.5.7 Performance of Air Intake Shaft

Description

The thermal/structural interactions (TSI) investigation in the air intake shaft will determine the closures of the shaft, as a function of the depth of the shaft; additional tests will correlate ultrasonic signal degradation with strain- and microfracturing-induced permeability increases in the shaft wall. The detailed shaft closure data will form the basis for verification of shaft closure calculations to determine the time for reconsolidation of shaft fill material and stress configurations around seals.

Justification

The large-scale TSI in-situ tests are designed to provide data against which the thermal and structural codes will be verified. The in-situ data will also directly influence the design of shaft seals and performance assessment of the seals. The in-situ data for air intake shaft closure are important for validating the calculations of shaft closure times. Detailed shaft closure data will be the basis for validating shaft closure models to determine stress configurations around seals and the time for reconsolidation of shaft fill materials. The correlation of microfracture to permeability will be used for performance-assessment evaluation of the effective seal conditions.

5.2.5.8 Intermediate-Scale Borehole Test

Description

For the intermediate-scale borehole test (Room C1, see Figure 1-4), a series of minor drilling studies were conducted within a previously mined room and entry. A small-diameter pilot hole was drilled horizontally through the pillar between Room C1 into Room C2 at roughly mid-height of the clear salt layer and roughly mid-length of the room. This pilot hole was overbored by a large-diameter (36-inch) core drilling operation. Prior to this, a three-dimensional array of instruments, closure gauges, extensometers, and stress meters, were installed in holes drilled from Room C2 and the 1420 entry drift into the region around the location of the large-diameter hole.

The test began in December 1990, and has been in operation since that time. Although a three-dimensional calculation of the test response was made prior to initiation, there are several important analytical aspects that remain to be completed as the test data become available. This is the first test where the stress meter results, which reflect changes in stress rather than absolute stress levels, can be clearly interpreted. Also, the test response will be recalculated after the test to improve the calculational capability of the three-dimensional codes.

Justification

Data are needed to resolve whether a scale effect can be observed in salt. Because resolution of the threefold discrepancy between the observed and calculated closure rates has been very difficult, a number of suggested causes of this discrepancy have been advanced. An explanation favored by mining engineers is that the classical scale effect observed in large underground openings in salt may be analogous to that observed in most hard rocks. Salt is not like a hard rock, in that it does not contain the joint sets which account for the scale effects in hard rock; hence the data obtained in the intermediate-scale test will help clarify the issue.

5.2.5.9 Panel Structural Test

Description

The structural behavior portion of the full-scale panel-response tests consists of instrumenting a full-sized, seven-room panel with geomechanical gauges. Knowledge of the panel response will permit judging the adequacy of predictions based on closure calculations of smaller arrays of rooms.

The structural gauges are in place and data are being collected. Closure points and extensometers have been installed as planned. Data on creep deformation have been obtained, and data from the remote closure stations and the multiple point borehole extensometers are currently being collected. Data collection will continue for up to five years, if possible. Analysis of the panel configuration will proceed as permitted by the availability of data.

Justification

The closure rates of storage rooms and the overall structural response of a storage panel have been based on data obtained from the site and preliminary design validation (SPDV) for the four-room test panel and access drifts. Other information about creep response of underground openings has been documented from in-situ tests performed for the technology development programs. Additional data will confirm the response of a seven-room panel and will provide supplemental information to the design validation study and long-term, disposal-area performance studies. Knowledge of the behavior of disposal rooms, panel pillars, barrier pillars, and access drifts in a seven-room panel will provide increased confidence in the long-term structural behavior of the disposal area and reduce some of the uncertainty associated with the response of an actual storage panel.

5.2.5.10 Test of Thermal and Structural Interactions

Description

The TSI tests are being conducted to provide the room-scale structural response data from a variety of stress and thermal conditions that exist throughout the WIPP underground experimental area. The resulting, extensive data bases will be used for validating the predictive models.

All of the TSI tests have been put in place, except those for phases two through four of the Room G (see Figure 1-4) test. These phases address the three-dimensional aspects of intersections of underground drifts and passageways and the fracture and potential failure of large salt masses.

Justification

Analyses of the data from the TSI tests are ongoing. At this point, the TSI tests are providing insight into the structural response of salt. These tests should continue as long as possible because they provide the principal basis for reducing uncertainty and establishing confidence in the structural predictions for performance assessment.

5.2.5.11 Integration of Rock-Mechanics Studies

Description

Integration and management of the numerous rock mechanics studies are required. Specific examples of integration studies include specification of future experimental areas needed for rock mechanics and

seals-tests assessment of rock mechanics phenomena observed in hydrologic tests, evaluation of the loading on shaft linings, and potential evaluations of the design lifetime for underground openings within the WIPP facility. Coordination of the planned underground R&D studies with the development of the *Comprehensive Underground Management Plan* (DOE, 1992d) for the WIPP facility is achieved by incorporating testing needs into the plan. Information is provided for backfilling studies planned for the WIPP facility and for plans for decommissioning of completed experiments.

Justification

Integration of the rock mechanics studies is a protocol process aimed at coordinating laboratory and field studies with associated modeling and analysis studies.

5.2.5.12 Mine-Support-System Technology and Demonstrations

Description

Support-system design and monitoring are done routinely. Numerous areas of data evaluation and interpretation require rock mechanics information and, in selected instances, the application of the computer codes developed to simulate the mechanical behavior of WIPP openings. The support system loading in Room 1 of Panel 1 (see Figure 1-4), and the maintenance approaches for assuring usability of access drifts throughout the time they must remain open will require detailed evaluations. Drifts in which proposed maintenance approaches will be validated will be likely candidates for numerical predictions and for evaluations of data from monitoring systems. Information from this study will be used in planning of monitoring systems and design of the maintenance approaches or support systems.

Justification

Support-system technology evaluations will help to assure that experiments can be safely carried to their completion and to assure that necessary underground operations can be carried out using best available technology.

5.3 Waste Interactions

Four activities are designed to provide information about the waste interactions within the disposal room. The first activity (Section 5.3.1 - Gas Generation Characteristics) evaluates the gas generation characteristics of the emplaced waste. Gas generation impacts disposal-room performance and fluid flow (both brine and gas) within various portions of the disposal system. The second activity (Section 5.3.2 - Radionuclide Source Term in Disposal-Room Brine) evaluates the concentrations of radionuclides expected in disposal-room brine. These concentrations are used (in conjunction with processes such as those expected within the Culebra Dolomite and a human intrusion borehole) to estimate the total quantity of radionuclides transported from the disposal room to the accessible environment under either undisturbed or disturbed conditions. The third activity (Section 5.3.3 - Waste Characterization) evaluates waste characterization results for the WIPP radionuclide and material inventories. The radionuclide inventory information is used in estimating the radionuclides released from the repository under long-term conditions; the material inventory information is used in estimating gas generation rates and potentials within the repository. The fourth activity (5.3.4 RCRA Constituents Source Term in Disposal Room Brine and Gas) evaluates the waste characterization information to determine the types and amounts of hazardous materials in the waste, and through testing, determine solubilities of the metal and organic waste material.

Each of the ongoing activities is supported by several studies that are listed in Table 5-3. Studies are further categorized as a laboratory test (L), field test (F), design task (D), modeling study (M), or protocol function (P). Test plans are prepared for laboratory tests and field tests; these are also listed in Table 5-3. Individual plans are typically prepared for all tests with waste and for major non-waste field tests. Generic plans are prepared for laboratory and field studies that do not warrant individual test plans. Test plans may be revised or supplemented as tests evolve.

5.3.1 Gas Generation Characteristics Activity

Gas production by the decomposition of cellulosic waste, corrosion of metals and radiolysis of TRU mixed waste all may impact the performance of the planned repository. Gas generation, working against creep closure and the consolidation of the WIPP disposal room contents, is the source of driving pressures that may prevent the complete closure of the disposal room, may cause room expansion, may drive volatile organic compounds (VOCs) out of the repository, may cause crack dilation or fracture initiation or both in the interbeds and marker beds, and may drive brine out of the disposal room, thus limiting radionuclide transport by isolating the waste from WIPP brines.

The generation of potentially detonable mixtures of gases and the transport of VOCs are also of concern during the operational period of the planned WIPP repository and are discussed in Section 4.3.3.

The objective of the gas generation program (GGP) is to develop a modeling capability for predicting gas generation species and their generation rates from the date of first emplacement throughout the period of regulatory concern.

The predictive model must work over a wide variety of materials; i.e., over the range of materials covering the potential repository inventories for the WIPP, over a wide range of chemical environments in the presence or absence of brines, and over a wide range of pressures. The gas generation models will then be either transferred directly or modified as necessary for use in evaluating disposal room performance, Salado flow and transport, and total system performance.

5.3.1.1 Model of Gas Generation

Description

Production and consumption of gas and water in the repository by metallic corrosion, microbial activity, radiolysis, reactions with proposed backfill additives, and formation of liquids or solids could affect brine inflow and outflow, disposal room closure, fracture dilation/initiation, and the likelihood of radionuclide release under undisturbed conditions or in the event of human intrusion. Performance assessment needs the ability to predict gas generation by the waste materials placed in the WIPP. This study will develop the necessary gas generation predictive capability.

This study will develop gas generation predictive models for gas species and rates of a wide variety of wastes from the date of first emplacement of these wastes through the end of the period of regulatory concern. Development and confirmation of the model rely heavily on the gas generation laboratory studies. Either the model or an appropriate derivative of the model will be incorporated in performance assessment of the WIPP repository.

Further detailed discussion of the objectives, technical approach, and rationale of the gas generation model can be found in the TNAD (DOE, 1992a).

Table 5-3. Waste Interactions Activities, Supporting Studies, and Associated Test Plans

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.3.1	**Gas Generation Characteristics Activity**		
5.3.1.1	Model of Gas Generation	M	NA
5.3.1.2	Laboratory Studies of Gas Generation	L	Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant, L. H. Brush, 1990.
5.3.1.3	Gas-Generation Experiments (Bin Tests) with CH TRU Waste	F	Test Plan Addendum #1: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests, M. A. Molecke and A. R. Lappin, 1990. Test Plan: WIPP Bin-Scale CH TRU Waste Tests, M. A. Molecke, 1990.
5.3.2	**Radionuclide Source Term in Disposal Room Brine Activity**		
5.3.2.1	Model of the Actinide Source Term	M	NA
5.3.2.2	Large-Scale Studies of the Actinide Source Term	L	See 5.3.1.2
5.3.2.3	Laboratory Studies of the Actinide Source Term with CH-TRU Waste	F	Test Plan: Actinide Source Term CH-TRU Waste Tests (To be developed).
5.3.3	**Waste Characterization Activity**		
5.3.3.1	Characterization of the Waste Inventory for the Compliance Source Terms	F	The Waste Inventory Characterization Program is described in the WIPP Waste Characterization Program Plan and the work is conducted by the waste generators at their sites.
5.3.4	**RCRA Constituents Source Term in Disposal Room Brine and Gas Activity**		
5.3.4.1	Hazardous-Organic-Constituents Degradation Rates and Reaction Products	L	Test Plan: Hazardous Organic Constituents Degradation Rates and Reaction Products (To be developed).
5.3.4.2	Characterization of VOC Transport out of Waste Containers	L/M	Combined Experimental-Computational Approach to Determine Volatile Organic Compound (VOC) Representativeness Throughout Waste Drum Headspace, EG&G Idaho, Inc., 1992 (In preparation).
5.3.4.3	Design of Alcove Test	F	Test Plan: WIPP In-Situ Alcove CH TRU Waste Tests, (To be developed)
5.3.4.4	Design and Testing of Alcove Gas-Barrier, -Management, and -Sampling Systems	F	See 5.3.4.2
5.3.4.5	Alcove Test Operations	F	See 5.3.4.2
5.3.4.6	Characterization and Preparation of Alcove Waste	F	See 5.3.4.2

1. D = Design Task
   F = Field Study
   L = Laboratory Study
   M = Modeling Study
   P = Protocol (data base management, integration of studies, etc.)

2. Test Plans are prepared only for laboratory and field tests
   NA: Test Plans are not applicable to Design, Modeling, and Protocol studies

Justification

A model developed from laboratory gas generation data is needed to predict gas generation in disposal room performance studies and performance-assessment evaluations. Production and consumption of gas and water in the disposal rooms — by anoxic corrosion, microbial activity, radiolysis, proposed backfill additives, and the formation of liquids or solids — could affect brine inflow and outflow from the disposal rooms, as well as affect the permeability of the disposal room contents and of the disturbed rock surrounding the disposal rooms. These factors, in turn, influence radionuclide release under undisturbed conditions, or in the event of human intrusion, and the migration of volatile organic compounds and other hazardous compounds away from the repository. The suitability of the model for these predictions is determined by comparison of results from it with the results of coupled materials-interaction experiments carried out with simulated TRU mixed waste in the laboratory and with CH TRU mixed waste in bin tests.

5.3.1.2 Laboratory Studies of Gas Generation

Description

This study develops chemical, mechanistic, and rate information on metallic corrosion, microbial degradation, and radiolysis, as well as known synergistic interactions of these processes with WIPP inventory waste materials. The laboratory studies provide a unique opportunity to develop mechanistic understanding of repository chemistry that can be directly applied to the gas generation model. Furthermore, this work supports the design and implementation of the gas generation program TRU waste tests.

These studies have already resulted in baseline information on generation rates from corrosion, microbial degradation, and radiolysis. Current studies include the corrosion of metals and radiolysis with various cover gas fugacities as required by the gas generation model. Studies have also been initiated investigating the impact of radiolysis on plastics and rubber with regard to converting these materials into a form acceptable for microbial degradation and, thus enhance the potential for further gas generation.

Production and consumption of gas and water in the repository by metallic corrosion, microbial activity, radiolysis, reactions with proposed backfill additives, and formation of liquids or solids could affect brine inflow and outflow, disposal room closure, fracture dilation/initiation, and the likelihood of radionuclide release under undisturbed conditions or in the event of human intrusion. This study will supply information necessary for the development of the gas generation model. Subsequently, laboratory tests will be developed to verify the gas generation model for the expected WIPP inventory and WIPP repository conditions.

Further detailed discussion of the objectives, technical approach, and rationale of the gas generation laboratory studies can be found in the TNAD (DOE, 1992a).

Justification

Production and consumption of gas and water in WIPP disposal rooms — by anoxic corrosion, microbial activity, radiolysis, and backfill additives — could affect compaction and permeability of the room contents, the rate of closure of the room, and the permeability of the surrounding rock formation, and thus influence radionuclide or hazardous material movement. Developing an understanding of these gas mechanisms from laboratory tests is the basis for constructing the gas generation model that is used for modeling the behavior of WIPP disposal rooms, the interpretation of

the bin tests, and for performance assessment. The laboratory studies quantify significant chemical processes under experimental conditions simulating repository conditions and address the effects of variations in physiochemical conditions on these processes.

5.3.1.3 Gas-Generation Experiments (Bin Tests) with CH TRU Waste

Description

Characterized CH TRU wastes will be tested (bin-scale tests) to evaluate degradation processes, gas generation species, and gas generation rates. The results of these studies will be compared with gas generation predictive models. Good agreement between experimental and modeling results will enhance confidence in the gas generation model, while poor agreement will identify areas that require further investigation in both the gas generation model studies and in the gas generation laboratory studies efforts.

Various portions of this study focus on bin-scale test design, bin hardware design, CH TRU experimental waste characterization, bin test operations, and bin-test data collection and analysis. Bin-scale test design determines the proper experiments to test the predictive capabilities of the gas generation model. Bin hardware design determines the proper bin test systems to safely achieve the objectives of the bin tests. CH TRU experimental waste characterization defines the initial bin materials inventory for comparison with the gas generation model. Bin test operations identifies the daily operations, maintenance and calibration required on the bin systems to safely conduct a scientifically valid experiment. Bin-test data collection and analysis compiles, documents, and analyzes the resulting bin data for comparison with the gas generation predictive model.

Production and consumption of gas and water in the repository by metallic corrosion, microbial activity, radiolysis, reactions with proposed backfill additives, and formation of liquids or solids could affect brine inflow and outflow, disposal room closure, fracture dilation/initiation, and the likelihood of radionuclide release under undisturbed conditions or in the event of human intrusion. This study provides a means of investigating gas generation mechanisms and rates with actual CH TRU waste materials that are targeted for disposal at the WIPP on a larger scale than possible with laboratory tests. This study also provides a means of observing possible synergistic effects that may not be apparent in the laboratory tests.

The test wastes will be contained in two types of specially designed steel bins. Type 1 bins are low pressure bins (0-0.5 psig operating pressure), nominally cubical, with an internal volume of about 42 cubic feet, and containing about five drum-volume equivalents of TRU mixed waste. An external humidification system will be used with the type 1 bins to simulate the humid conditions expected in a repository disposal room after the room has been sealed. Each type 1 bin has a number of access ports that can be used to monitor the pressure, provide pressure relief, sample gases, inject tracer gases, and purge with inert gases, as appropriate. During the tests, the bin will remain in the overpack (the metal waste box) in which it was shipped. The purpose is to provide both primary and secondary confinement for the radioactive material on arrival at the WIPP. The lid of the overpack will be replaced with a special lid designed to accommodate connections between the access ports in the bin and the various instruments used in the tests. A data acquisition system will control and record signals from instruments such as thermocouples, differential pressure gages, valves for relieving gas pressure, gas flow rate and volume gages, solid-state oxygen sensors, etc.

The type 2 bin design is being developed. This bin is for testing gas generation from wastes under pressurized humid and brine-inundated conditions intended to simulate postclosure conditions in the repository. The bin operating pressure may range up to lithostatic conditions (nominally 2200 psi or

15 MPa) and, unlike the type 1 bin operation, will not be vented during operations. The generation of gases within the waste will be allowed to occur unimpeded by operator action or constrained by bin design pressure. Access ports will be available in type 2 bins for establishing initial test conditions within the bins, and for brine and gas sampling and establishing conditions during and at the completion of the tests.

The bin-test program consists of three tiers of tests: (1) specifically planned tests, (2) conditionally planned tests, and (3) contingency tests. Between 19 and 44 bins of CH TRU waste and six-to-ten bins of simulated waste are anticipated to be tested in the specifically planned and conditionally planned tests. The three tiers of bin tests are described below.

Specifically Planned Tests

The specifically planned tests are those individually identified as needed to reduce uncertainty and increase confidence in the ability to predict (1) gas generation rates and species; and (2) release rates for volatile organic compounds. The DOE plans to conduct these tests with 19 bins of actual transuranic waste, six bins of simulated waste, and eight reference bins, for a total of 33 bins. Both type 1 and type 2 bins will be used in these tests. The reference bins will be used to obtain information on the bin itself and its components, such as the behavior of its paint coating or the interaction between the paint and the plastic liner of the bin.

Eight of the bins with TRU mixed waste will be used to investigate single gas generation mechanisms. Three of these — two humid (type 1) and one inundated (type 2) — will contain paper and other cellulosic waste and will be used to investigate gas generation by microbial activity. Three bins — two humid (type 1) and one inundated (type 2) — will contain corrodible metallic waste and will be used to study rates of corrosion under conditions expected in the near term, after ventilation stops, and those expected after closure, over the long term. Two type 2 bins (one humid and one inundated) will contain solidified inorganic sludges and will be used to investigate radiation-induced generation of gases.

Two bins (type 2) with TRU mixed waste will be used to investigate binary reaction mechanisms — namely, the interaction of radiation-induced decomposition and sludge leaching with microbial activity. One of these bins will be humid and the other one inundated.

Six bins with TRU mixed waste (type 2) will be used to investigate potential interactions among a variety of waste materials. All of these bins will contain some solidified sludge. The purpose is to investigate interactions among all three of the major gas generation mechanisms (the corrosion of metals, radiation-induced decomposition, and microbial activity).

The last three TRU mixed waste bins will be filled with glass waste (type 1). These bins will be used mainly as an initial check of the reliability of the gas generation model. The gas generation mechanism expected in these bins is the radiation-induced decomposition of the plastic liner of the bin. (Six simulated waste bin tests and eight reference bins are also included in the specifically planned portion of the bin test program.)

Conditionally Planned Tests

The conditionally planned tests are tests that will be conducted if the results from the specifically planned tests have not adequately reduced the level of uncertainty about gas generation and release rates. If these tests are needed, they will be conducted with up to 25 additional bins of transuranic

mixed waste and up to four additional bins of simulated waste, for a total of up to 29 additional bins. All of the bins with transuranic mixed waste are likely to be type 2 bins.

Twelve of these bins with waste likely will be used to examine the effects of waste modifications. The bins will be divided into three groups: cellulosic waste, metallic waste, and mixed waste; two different engineered modifications for each type will be investigated. For each modification, one humid and one inundated bin will be used.

Nine of the bins included in the conditionally planned tests likely will be used to investigate the statistical variability of interactions in wastes containing large and small quantities of solidified sludge wastes. The last four bins with waste likely will be used to investigate binary gas generation mechanism not addressed in the specifically planned test. These paired mechanisms are (1) microbial activity and corrosion and (2) radiation-induced decomposition and corrosion. (Four additional simulated waste bin tests are included in the conditionally planned bin test program. No additional reference bins are included in the conditionally planned tests.)

Contingency Tests

Contingency tests may be conducted if the results from the planned tests are unexpected, additional tests are mandated by regulators, or further investigation of engineered modifications of the waste form are needed to enhance the predicted performance and facilitate the demonstration of compliance.

Further detailed discussion of the objectives, technical approach, and rationale of the gas generation CH TRU waste experiments/bin tests can be found in the TNAD (DOE, 1992a).

Justification

The function of the bin tests is to obtain data for gas generation rates and total volume potential for evaluating the suitability of the gas generation model. Gases generated by radioactive wastes may significantly affect repository pressurization and disposal room conditions, and therefore, the potential for releases caused by either human intrusion or gas and fluid flow through the surrounding Salado Formation. Data from the gas generation experiments will be used to evaluate the suitability of the gas generation model (Section 5.3.1.1), which will be used in the performance assessment.

5.3.2 Radionuclide Source Term in Disposal Room Brine Activity

The actinide source-term studies are designed to provide a model for predicting of the concentrations of individual actinide-containing species in disposal-area brine. Actinide concentrations are a priority need for evaluating compliance with requirements in the disposal regulations. The principal types of mobile actinide-bearing species in brine are expected to be dissolved ions in several possible oxidation states, dissolved complexes of these ions with ligands, and colloids. The identities and concentrations of these species are important parameters for the mass transport models that may be used to evaluate regulatory compliance. Specifically, the magnitude of retardation of radionuclide transport in brine by sorption onto surfaces of geologic media is species-dependent, and the release quantities depend on the concentrations in solution. Emphasis is on actinides; other radionuclides may be studied, as necessary.

Development of a model for predicting actinide concentrations will be advanced by answering the following scientific questions. What would be the concentrations of the actinide-bearing species in brine under the variety of chemical conditions that could exist within the heterogeneous waste? What are the oxidation states of these species in brine? What is the temporal behavior (e.g., changes in

concentrations and sizes) of colloids? How do all waste constituents and other room contents, including room backfill materials, affect the types of species and their concentrations? In particular, how do ligands originating in the brine and in the waste affect the concentrations of complexes? How does sorption on backfill materials affect species identities and concentrations? If the actinide-bearing species reach the Culebra water-bearing zone, what would be their concentrations in this changed chemical environment? How are predictions of these parameters for ranges of conditions best embodied in a predictive model for use in performance-assessment calculations? Technical Information needs related to these questions are treated in more detail in the TNAD (DOE, 1992a). Additional questions may become apparent as the work proceeds.

5.3.2.1 Model of the Actinide Source Term

Description

An actinide source-term model is being developed to predict the concentrations of mobile actinide-containing species, including colloids, in brine in the waste disposal area. Model development is done with the aid of information from the published literature and data provided by the actinide source-term laboratory studies (Section 5.3.2.2). Results from the actinide source-term waste tests will be used to test the validity of the model for predicting source-term information for actual waste under disposal conditions. The model will reflect the complex chemical behavior of these elements, including formation of actinide-containing colloids and sensitivities to parameters such as Eh, pH, and the concentrations of organic and inorganic ligands that can act as complexing agents. Numerical models that incorporate these parameters and thermodynamic relationships are evaluated in the modeling effort.

Justification

The source-term model takes data from the laboratory and other sources and provides the mathematical description needed for performance assessment. Predicted species identity and concentrations of mobile radionuclides in brine are parameters required for calculating long-term radionuclide transport. Species identity, including radionuclide-containing colloids, is important for predicting radionuclide mobility. The suitability of the model for these predictions is determined by comparing its results with the results of coupled materials-interaction source-term waste tests.

5.3.2.2 Laboratory Studies of the Actinide Source Term

Description

Laboratory studies of actinide chemistry are carried out in brines having compositions representative of those expected in the waste disposal area. This work includes determination of concentrations, stability constants, solubilities, and sorption properties of individual actinide-containing species. Sensitivities to Eh, pH, and the concentrations of organic and inorganic ligands that can act as complexing agents will be determined. The work is divided into three groups: solution chemistry studies, colloid studies, and sorption studies. The studies are supported by information on the chemical environments in the disposal rooms obtained from chemical studies in the gas generation program.

Information from these studies is needed to develop an actinide source-term model for predicting actinide concentrations in disposal-room brine. Performance assessments have shown that concentrations of isotopes of actinide elements are priority data needs for evaluating compliance.

This information is also needed to aid in the interpretation of results from the actinide source-term waste tests to be done with TRU waste. The interpreted results will be used to test the validity of the actinide source-term model.

Justification

Information from this study is needed to develop the source-term model (Section 5.3.2.1) for performance assessment. The source-term model will include isotopes of plutonium, americium, neptunium, thorium, and uranium. The model will also reflect the complex chemical behavior of these elements, including formation of colloids containing radionuclides, and the sensitivities of these elements to parameters such as Eh, pH, and the concentrations of organic and inorganic ligands that can act as complexing agents. Laboratory studies with plutonium, americium, neptunium, thorium, and uranium, or with oxidation-state analogs of these elements, will allow quantification of the effects of Eh, pH, and ligand concentrations on the concentrations of all mobile radionuclide-containing species.

Information from this study is also needed to interpret results from the source-term waste tests (Section 5.3.2.3). The interpreted results will be used to test the validity of the source-term model generated in Section 5.3.2.1.

5.3.2.3 Large-Scale Studies of the Actinide Source Term with CH TRU Waste

Description

The actinide source-term waste tests are designed to measure the species and steady-state concentrations of actinides, complexing agents, and other chemical reactants in contact with candidate backfill materials and TRU mixed waste in simulated WIPP brine. These tests will include multiple drum-scale and liter-scale tests. Drum-scale tests will be done with highly heterogeneous waste types, such as combustibles and metals. Liter-scale tests will be done with more homogeneous waste types, such as sludges and pyrochemical salts. Currently, 15 drum-scale and 39 liter-scale tests are planned to meet these objectives. Actinides will be added to ensure that concentrations in the brine will not be limited by the actinide inventory the waste. The extent to which the interactions of brine, design-basis waste types, and backfill additives influence the species identities and concentrations of actinides as a function of time will be determined by sampling the brine at regular intervals.

Concentration data from these tests will be used to test the validity of the actinide source-term model, which will be developed from results of laboratory studies and used as input for performance-assessment calculations. Preliminary performance assessments have shown that concentrations of isotopes of the actinide elements are important for evaluating compliance with the disposal regulations. The actinide source-term waste tests differ from the bin-scale tests in that the test matrix is designed to isolate waste parameters that may influence concentrations of mobile actinides rather than rates of gas generation. In addition, the test containers will be agitated to promote thorough mixing of the contents. Agitation is expected to increase gas-generation rates. These elevated rates are not expected to be representative of actual waste disposal conditions in the planned WIPP repository. Nevertheless, headspace gases will be sampled at regular intervals to track chemical and microbiological reactions in the test containers.

The conduct of these tests includes waste characterization and preparation, test operation, and data analysis. Each type of waste to be used in the actinide source-term waste tests will be characterized for variables that are expected to influence actinide concentrations in WIPP brine. Included among these variables are total radioactivity, organic content, quantity and type of sorbents, metallic content,

and physical state of the actinide compounds. The actinide source-term waste tests will be carried out by filling containers with TRU waste types, adding actinides, saturating the containers with brine, and sealing the containers to prevent significant gas leakage. The containers will be agitated throughout the tests, and the brine and headspace gas will be sampled at regular intervals. The brine will be analyzed for actinide concentrations and oxidation states, actinide-containing colloids, and concentrations of other chemical reactants that can influence actinide concentrations. Headspace gas will be analyzed for products of chemical and microbiological reactions to track all anticipated reactions that are expected to influence actinide concentrations.

Justification

Concentration data from these tests will be used to test the validity of the source-term model, which will be developed from laboratory data (Section 5.3.2.1). The actinide source-term waste tests differ from the bin-scale tests in that the test matrix is designed to isolate matrix qualities that may influence actinide solubility rather than gas generation.

5.3.3 Waste Characterization Activity

Information regarding the quantities and compositions of the inventories of both existing and to-be-generated TRU mixed wastes is essential. Characterization of the existing waste inventories within the DOE system must adequately define the variability in the radionuclide content of these wastes. However, the characterization must also be adequate to define the inventory-scale variability in other waste-related parameters of interest in long-term repository performance, such as gas generation potentials, general mechanical properties, and factors possibly affecting the concentrations of radionuclides in brine. Characterization of existing inventories is not adequate. In order to define a realistic range of final WIPP inventories the possible ranges of both inventories and characteristics of to-be-generated wastes must also be adequately estimated. Characterization of both existing and to-be-generated waste inventories must, in combination with detailed characterization of experimental wastes, TRU mixed waste experiments, numerical modeling, and inventory estimates, be sufficient to define the actinide source term under a realistic range of possible long-term repository conditions.

5.3.3.1 Characterization of the Waste Inventory for the Compliance Source Terms

Description

The inventory of radionuclides and regulated hazardous waste to be emplaced in the WIPP will be characterized to the extent necessary to predict the potential migration of these constituents. This information will be incorporated into the performance-assessment models to define the quantity of radionuclides and hazardous chemical constituents that could potentially escape from the repository. This study will define the radionuclide and hazardous materials inventory that will be used as a source term in compliance evaluations. This study will also define the hazardous constituents that are predominant in the waste.

Performance-assessment analyses and sensitivity studies require a radionuclide source term and an inventory of the constituents of RH and CH waste packages that may affect gas generation and radionuclide transport. This study will update the radionuclide source term for RH and CH waste, based on updated information from the generator sites for each cycle of performance assessment. The inventory of organic and metal constituents that may affect gas generation by corrosion, biological processes, and radiolysis will be developed for the RH waste packages and will be updated for the CH waste packages.

The character of the hazardous wastes to be emplaced in the WIPP has been defined largely through knowledge of the materials and processes associated with the generation of the waste and through limited sampling programs at the generator sites. The DOE has developed the WCPP (DOE, 1992c) and the waste analysis plan (WAP), which is included in the RCRA permit application (DOE, 1993b), to define waste characterization studies that will be performed to confirm the current waste descriptions. The WCPP (DOE, 1992c) addresses characterization studies to be performed in support of both the 40 CFR Part 191 and the RCRA compliance programs. The WAP is designed to specifically address RCRA waste characterization requirements, including the need to define the composition and quantity in the waste of hazardous constituents that might migrate beyond the unit boundary.

Justification

Waste characterization information is needed to confirm DOE's waste-composition estimates, to meet the waste characterization requirements of 40 CFR 264.13, and to support modeling to demonstrate compliance with the no-migration standard of 40 CFR 268.6 and with the disposal regulations (40 CFR 191, Subparts B and C).

5.3.4 RCRA Constituents Source Term in Disposal Room Brine and Gas Activity

The objective of this activity is to understand the composition and behavior of hazardous constituents in the underground waste-emplacement rooms. Understanding emission of gases from waste containers, including gas generation rates, is also a part of this work. These studies are designed to provide confirmatory information for gas generation modeling and will help to define the source term used in modeling evaluations of the behavior of the planned repository.

This set of studies will evaluate migration of hazardous constituents by liquid and gas-phase transport. Factors evaluated will include the solubilities of hazardous constituents in brine, equilibrium vapor pressures of organic constituents, the potential for the formation and transport of colloids, and phase partitioning. Bin and alcove studies will be performed to gather data in simulated and actual repository environments. The results of the bin and alcove studies will be evaluated to determine whether the modeling estimates of the quantities and chemical compositions of gases in waste-disposal rooms can be confirmed. Definition of the source term will set upper bounds on the masses of hazardous constituents that can be transported by a unit volume of brine or gas.

The alcove test(s) will use TRU mixed waste contained in 55-gallon steel drums. The drums will contain only unmodified, contact-handled TRU mixed waste, without additives or brine. The tests will replicate, as closely as possible, the environment expected to be present in the WIPP during waste-emplacement operations. A gas barrier must be installed in the entrance to a test alcove to seal the alcove. The plan currently calls for the emplacement of waste in a single alcove; the filled alcove will not be backfilled. An additional alcove test using solidified sludge wastes may also be performed, as a contingency, if sufficient solidified sludge cannot be made available for the first alcove. A reference alcove (with a gas barrier) is planned as a reference basis for the alcove(s) containing TRU waste. Finally, an additional alcove may be constructed for annual demonstrations of waste retrievability. The drums in this alcove would not contain TRU waste.

5.3.4.1 Hazardous-Organic-Constituents Degradation Rates and Reaction Products

Description

The organic compounds listed by the EPA as hazardous are predominantly hydrocarbons or chlorinated hydrocarbons. These compounds are thermodynamically unstable and tend to react to form an assemblage of stable compounds such as carbon dioxide, methane, water, and chloride ions. Hazardous organic constituents will degrade by a combination of chemical and microbial processes, often involving the formation of intermediate degradation products. These intermediate degradation products usually include non-hazardous hydrocarbons such as oxalate, acetate, and carboxylic acids, but may also include other hazardous compounds. For instance, trichloroethylene has been shown under some conditions to form trichloroethane and vinyl chloride as intermediate degradation products, which are also hazardous. The persistence of these primary and secondary hazardous compounds is dependent upon the rates of these degradation processes and are usually controlled by the specific microbe population and the rates of microbial activity.

Factors affecting microbial degradation rates of these organic constituents in the repository environment include pH, dissolved oxygen concentration, availability of macro and trace nutrients, salinity, temperature, and concentrations of compounds that are toxic to specific microbes. Near-neutral pH conditions are optimal in most cases, although there are specific strains of microbes that can adapt to a wide range of pH conditions. Dissolved oxygen concentrations are important in determining the types of organisms present in a given environment. Types of organisms can range from strict aerobes that need oxygen to strict anaerobes that are poisoned by oxygen. Facultative microbes can adapt to a wider range of dissolved oxygen conditions. Macro nutrients (nitrogen, phosphorous, and potassium) and, to a lesser extent, micro nutrients (copper, zinc, iron, etc.) must be present at optimal concentrations to maximize microbial degradation rates. High concentrations of toxic metals such as mercury can inhibit microbial activity. Within certain limits, microbial activity increases exponentially with temperature.

Actual degradation rates are controlled by site-specific environmental conditions so that quantitative rates cannot be determined without additional site investigations and experimental degradation rates. However, numerous experimental investigations of the degradation rates of the contaminants of concern in a wide range of environments have been performed. Although none of these degradation rates was obtained in the WIPP repository environment, these studies provide an approximate range of degradation rates for specific contaminants in various environments. These published degradation rates will serve as the basis for identifying ranges of degradation rates for use in the RCRA compliance model and to identify the need for additional experimental data.

Justification

The chemical instability of most hazardous organic constituents suggests that these compounds will remain hazardous only for a finite period of time, after which they will degrade into harmless substances. It would thus be overly conservative to assume that these hazardous compounds will persist indefinitely. Consideration of degradation processes, however, requires that defendable degradation rates be obtained either from existing literature values or from new experimental data. The potential for the formation of hazardous degradation products will also be evaluated. Existing literature values will be evaluated to determine their suitability for use at WIPP and to define the need for any additional laboratory data.

5.3.4.2 Characterization of VOC Transport Out of Waste Containers

Description

The goal of this study is to evaluate whether a single VOC headspace sample taken from within a drum liner is representative of the entire void space of the waste container. A model is being developed to predict VOC concentrations throughout a waste drum and to evaluate whether a drum headspace sample is representative of the entire void space in a waste drum. The model simulated VOC transport mechanisms within a waste drum. Model results will be compared to data collected from drums containing simulated and actual TRU waste.

A series of laboratory-scale experiments is being performed to study VOC transport mechanisms in drums containing simulated and actual waste and to provide sufficient data to develop and test the model. This work includes studies of the diffusivity and permeability of some pure VOCs and some mixtures of VOCs through polyethylene; values are being measured and compared with those reported in the technical literature. The diffusion of VOCs from sealed polyethylene bottles is also being investigated. In addition, the VOC-adsorption capacity and transport properties of carbon composite filters normally used on waste drums are being measured.

Justification

The no-migration determination for the WIPP test phase (EPA, 1990a) requires that all layers of confinement in a waste container must be sampled until the DOE can demonstrate to the EPA, based on data collected, that sampling can be safely reduced. Results from this study will support this demonstration.

Information describing the effectiveness of waste packaging materials in limiting the movement of VOCs and the VOC-adsorption capacity and transport properties of carbon composite filters will be used in predicting the quantities of VOCs that will be emitted from waste drums, once the drums are emplaced in the WIPP underground. The accuracy of these predictions will be confirmed by the results of alcove-scale tests.

5.3.4.3 Design of Alcove Test

Description

One alcove test with 1050 drums of CH-TRU mixed waste is specifically planned and one additional alcove for solidified sludge wastes is included in contingency plans for sludge wastes. The primary objective of the specifically planned test is to develop an understanding of the amounts and types of gases (including VOCs) that will be released into the alcove head-space by leakage through waste container lid seals, lid gaskets, and filters. This test will mimic what will happen in a disposal room prior to the room being backfilled. This study will design the test alcove, the gas barrier used to close the alcove, and the gas management/sampling system used to obtain gas samples from the alcove during the test period. The gas barrier, in addition to effectively sealing the alcove, must also support the need to allow the retrieval of waste from the alcove should that be necessary. The *Waste Retrieval Plan for the Waste Isolation Pilot Plant* (DOE, 1993a) discusses the approach that will be used to determine the need to retrieve, and the approach that would be used to remove the waste from the alcove.

Justification

To ensure operational safety, the amount of gas (including VOCs) that will emanate from the waste drums into the disposal rooms while workers are in the vicinity of the filled disposal rooms during waste emplacement operations must be known. Further, the quantities of gases that might be released through the mine ventilation system during waste emplacement must be evaluated. Information obtained from the alcove test(s) will support evaluations of operational safety and environmental impacts.

5.3.4.4 Design and Testing of Alcove Gas-Barrier, -Management, and -Sampling Systems

Description

The first major alcove test effort is to design and test an alcove gas barrier to minimize the escape of gases from the alcoves. A trade-off study, preliminary design, and final design with construction specifications have been completed and reviewed. The current design uses a reinforced concrete and steel sleeve that would be installed in the entrance to an alcove. Construction and testing of the gas barrier are needed to validate this concept prior to using this barrier in tests with radioactive waste. Test planning and instrumentation evaluations are an integral part of the development and demonstration of this technology.

Additionally, a gas management system must be designed to support the sampling and analysis of the alcove atmosphere over the life of the experiment.

Justification

Initiation and conduct of the WIPP alcove test are dependent on the successful design, fabrication, and testing of alcove gas barriers and sampling system. Without these barriers, the gases generated from TRU mixed waste degradation processes would quickly leak out of the alcoves, providing minimal interpretable data. The gas management system will allow sampling of the gases entering the alcove headspace due to leakage out of the drums through the lid closure system and filters.

This study is related to the disposal room model and data base study (Section 5.2.1.5), alcove test design (Section 5.3.4.2), and room-scale test feasibility analysis (Section 5.2.1.8).

5.3.4.5 Alcove Test Operations

Description

The alcove test program will be shared by all related scientific, engineering, operations, analytical, safety, management, review, and regulatory participants. The test program includes periodic coordination, test operations (waste characterization, special preparations, transportation, technical, engineering, and mining studies; test gas and instrumentation analyses; and safety control), and gathering and reporting of test data. Alcove sampling and analysis techniques for individual gas components are expected to be patterned on those initially developed for the bin-scale test.

Initiation of a single alcove test will depend on (a) evaluation of the existing gas-barrier and instrumentation designs in light of the increased focus on the disposal phase and transitional timeframe; (b) successful development and demonstration of an effective gas-barrier design; (c) preparation of a modified test plan for an alcove test. A second alcove test using TRU mixed waste may be performed. This second test is part of the "contingency test program."

In the absence of timely development of waste-characterization capabilities for solidified sludge wastes, or in the event of a decision not to wait for the development of same, two options exist: (a) conduct alcove tests, one with solid waste (everything but solidified sludges) and later test with either full mix or with solidified sludges only; or (b) conduct one alcove test with solid wastes, and incorporate solidified sludge behavior into the gas release model on the basis of smaller-scale test data.

Justification

The waste characterization program will gather data about the gases that are present inside drums, but will not provide information about the effectiveness of drum seals and filters in retarding the release of gases from the drums. Containers currently being used to store the TRU mixed waste at the DOE waste generation and storage sites are closed with a lid and closure ring or band. Some of the drums also have a closure gasket between the drum and lid that is designed to be permeable to gases. Additionally, some of the drum lids are fitted with carbon-composite filters. The effectiveness of a drum in containing gases is a function of the effectiveness of the lid seal, gasket effectiveness, and filter effectiveness in appropriate combination. The primary reason for the alcove test is to allow the DOE to measure in a macroscopic manner (1,050 drums) the overall emissions of gases from an array of drums having the various sealing and gas filtration configurations.

5.3.4.6 Characterization and Preparation of Alcove Waste

Description

TRU mixed wastes used in the WIPP alcove test program must be adequately characterized for waste-component "controlling variables." Characterization consists of weighing and visually evaluating the contents of individual waste drums, analyzing some of the contents, and applying process knowledge using real-time radiography, radioassay, and the other techniques that would be used for characterization of waste for disposal. Waste characterization and associated preparation work are to be conducted by the waste generator sites producing (or storing) the wastes and preparing them for shipment to the WIPP for testing. The WCPP (DOE, 1992c) describes this work.

Justification

TRU wastes used in the WIPP alcove test program will be characterized for waste component "controlling variables" so that gas test data may be interpreted and modeled.

This study is related to engineered alternatives modeling (Section 5.2.1.6), gas generation characterization (Section 5.3.1), radionuclide concentrations in disposal room brine (Section 5.3.2), performance-assessment data base and conceptual modeling, repository and shaft systems modeling, and consequence analysis.

5.4 Human Intrusion

The EPA gives specific guidance with 40 CFR Part 191 for considering inadvertent human intrusion. The EPA assumes that exploratory drilling for resources is the most severe intrusion that must be considered (U.S. EPA, 1985c). Determining the probability of intrusion poses questions that cannot be answered by numerical modeling or experimentation. Projecting future drilling requires knowledge about complex variables such as economic demand for natural resources, institutional control over the site, public awareness of radiation hazards, and changes in exploration technology. Extrapolating current trends 10,000 years into the future requires expert judgement.

Given that an intrusion occurs, the effects of the intrusion must be considered. The intrusion event is characterized by the drilling of a borehole that affects the repository contents such as the removal of these contents in drill cuttings, eroded material, and drilling fluid. Processes set in motion by the drilling can include injection of gas and brine from an underlying brine reservoir into the repository and injection of gas and brine from the repository into the overlying formations, principally the Culebra Dolomite Member of the Rustler Formation. The characteristics of the borehole itself are included in the modeling.

Information needed includes the rate of future intrusions and the amount of cuttings, cavings, and collapsed material that are released directly to the surface during the intrusion event. If transport in the Culebra and that transport is governed by double-porosity flow, then the direct release to the surface still is expected to dominate the total release because the transport process through the Culebra delays and limits the releases along that pathway. If, on the other hand, transport in the Culebra is governed by single-porosity, fracture-only flow, then subsurface release through the Culebra could dominate direct releases; properties of the intruding borehole become important in this case.

Each of the ongoing activities is supported by several studies that are listed in Table 5-4. Studies are further categorized as a laboratory test (L), field test (F), design task (D), modeling study (M), or protocol function (P). Test plans are prepared for laboratory tests and field tests; these are also listed in Table 5-4. Individual plans are typically prepared for all tests with waste and for major non-waste field tests. Generic plans are prepared for laboratory and field studies that do not warrant individual test plans. Test plans may be revised or supplemented as tests evolve.

5.4.1 Human Intrusion Modeling Activity

Thus far, human intrusion scenarios are the only scenarios for which preliminary performance-assessment calculations have predicted releases to the accessible environment in the 10,000 years after disposal. Some of these scenarios include the case in which a breach borehole extends into the Castile Formation below the Salado Formation and into a pressurized brine pocket in the Castile, that may partially extend beneath the repository. Thus, performance-assessment models must predict the behavior of a pressurized brine pocket beneath the repository and the transport of materials from the repository, up the breach borehole to the surface (in the case of drill cuttings) or laterally through the units overlying the Salado, primarily through the Culebra, to the accessible environment. Flow and transport in the Culebra may be altered by brine and gas from either the Castile brine pockets or from the repository being injected into the Culebra. The questions of interest are as follows. What would be the flow rates into the breach borehole be if a brine pocket is penetrated? How rapidly would the flow rates decrease in time? How would partial desaturation of the Culebra along the flow path affect flow and transport in the Culebra? No additional modeling or testing are planned for Castile brine reservoir characterization. Performance-assessment sensitivity studies performed in 1989, 1990 and 1991 indicate that the remaining uncertainties in Castile brine reservoir characteristics do not significantly affect the results of the performance assessment.

5.4.1.1 Culebra Desaturation Resulting from Human Intrusion

Description

Current modeling of flow and transport in the Culebra assumes saturated flow conditions. However, injection of gas dissolved in the Castile brine pockets and free gas in the repository into the Culebra could result in unsaturated conditions in the Culebra. These effects have not been evaluated. Transport model development (Section 5.1.1.3) will consider the effect of unsaturated conditions.

Table 5-4. Human Intrusion Activities, Supporting Studies, and Associated Test Plans

Chapter 5 Section	Title	Study Type[1]	Test Plan[2]
5.4.1	Human Intrusion Modeling Activity		
5.4.1.1	Culebra Desaturation Resulting from Human Intrusion	M	NA
5.4.2	Probability of Human Intrusion Activity		
5.4.2.1	Expert Panels (Probability of Human Intrusion vs. Time)	M	NA
5.4.3	Cuttings Release Parameters Activity		
5.4.3.1	Laboratory Studies of Drill Cuttings	L	Test Plan: Drill Cuttings Laboratory Studies (To be developed)
5.4.3.2	Model of Drill Cuttings	M	NA

1. D = Design Task
   F = Field Study
   L = Laboratory Study
   M = Modeling Study
   P = Protocol (data base management, integration of studies, etc.)

2. Test Plans are prepared only for laboratory and field tests
   NA: Test Plans are not applicable to Design, Modeling, and Protocol studies

Justification

Brine and gas is expected to be discharged into the Culebra as a result of human intrusion. The possibility of unsaturated conditions may have appreciable effect on the flow out the borehole and to the site boundary due to the possible significant gas volume fraction of the total brine-gas mixture. In addition, the transport in the Culebra may be affected due to different flow rates and different chemical conditions associated with gas. Therefore, the effect of gas and brine discharging into the Culebra should be evaluated.

5.4.2 Probability of Human Intrusion Activity

Human intrusion into a geologic repository must be considered a possibility. In the guidance to the disposal regulations, the EPA requires the impact of inadvertent human intrusion to be considered when calculating cumulative releases to the accessible environment. All performance-assessment calculations to date indicate that only human intrusion scenarios (exploratory drilling) contribute to the cumulative releases to the accessible environment in the 10,000 years after disposal. Research addresses the following questions. What might be the future states of society and how might they intrude on the planned repository in the future? How can the question of the probability over time that future societies might inadvertently intrude upon the WIPP be addressed in a systematic fashion? What systems of markers and protective barriers might deter inadvertent human intrusion, given the possible states of society? What type of records system might be able to convey the appropriate information to the potential intruder in a timely fashion to deter intrusion? To what extent might markers, protective barriers, and records reduce the probability over time of inadvertent human intrusion?

5.4.2.1 Expert Panels (Probability of Human Intrusion vs. Time)

Description

Expert judgment is the best professional opinion of experts in a particular field. The amount of judgment required ranges widely. If there are no data and no possibility of obtaining data, expert judgment is used to estimate the range within which data will occur and the degrees of belief about how the data will be distributed over the range. However, measured data are preferred. The development of a conceptual model to describe a natural phenomenon requires judgment to examine the current state of knowledge and to produce a coherent model of the behavior of a natural system. Judgment is required in developing mathematical and computational models to represent conceptual models. Before data are ever collected from an experiment, judgment is used in developing the hypothesis to be evaluated and in establishing the experimental conditions. Experimental data require interpretation for the computational models.

A formalized process has been established for eliciting judgments from expert panels, and the WIPP performance-assessment program uses expert-judgment panels. Expert panels provide probability distributions for the calculations on the probability of future human intrusion at the WIPP and on the effectiveness of informational markers in deterring human intrusion. Expert panels have provided cumulative probability distributions of concentrations for the various radionuclides in the repository environment and the retardation of radionuclides in the Culebra. Expert panels will not be used as a substitute for experimental data when appropriate, practical experiments can be performed.

Justification

Expert judgment is the only means of assigning probabilities to human intrusion scenarios. Expert panels have provided judgments about the societies of the future and principles to guide design of passive institutional controls. Such controls are mandated by the assurance requirements of 40 CFR Part 191. The effectiveness of these controls, expressed as a probability of intrusion, is necessary for developing the CCDF; probabilities of intrusion over time are based on the judgments of the expert panels.

5.4.3 Cuttings Release Parameters Activity

The objectives of this activity are to provide an experimental basis for modeling entrainment of drill cuttings, and if necessary, modify the existing model to agree with the data. Drill cuttings entrained in the drilling fluid during a human intrusion of the planned WIPP repository would be carried to the surface, releasing radioactive material (along with intentionally removed core material). The amount of radioactive material released in cuttings would depend on the volume of waste removed. For waste forms with low material strength, material adjacent to the borehole wall might erode into the hole, because of scouring by the drill fluid. Rapid release of entrapped gases from relatively impermeable waste forms might also cause collapse of material into the borehole. Under both circumstances, the expulsion of borehole waste would enlarge the borehole. A greater volume of waste would be removed than expected on the basis of the initial borehole diameter alone. How TRU mixed wastes are likely to be altered by biological and chemical processes as a function of time, what effects these changes are likely to have on the strengths and permeabilities of the various waste forms, and how these changes, in turn, will impact the amount of material brought to the surface as a result of drilling into the repository must be examined.

5.4.3.1 Laboratory Studies of Drill Cuttings

Description

Laboratory tests are required to define and quantify the properties of simulated waste that contribute to borehole enlargement during a human intrusion. The amount of radioactive cuttings released from a borehole during penetration of the WIPP repository is determined from the volume represented by the cross-sectional area of the borehole multiplied by the thickness of the waste layer. Drill cuttings are entrained in the drilling fluid and are then carried to the surface, constituting a release of radioactive material. A concern in estimating the extent of such releases is that material adjacent to the borehole wall may be eroded or may spall off (collapse) into the borehole and cause the diameter of the borehole to become greater than that normally observed in salt-drilling operations. Erosion or spalling of the waste during drill penetration would cause a greater release of cuttings.

Some of the material properties of the waste needed to define the diameter of a borehole are its shear strength for erosion, permeability, surface roughness, and spall strength. Because radioactivity has no influence on these properties, tests to study them can be performed on nonradioactive simulated waste. A complication in experimental sample definition, however, is that once emplaced in the repository, the waste is likely to be continually altered with time by biological and chemical processes. Therefore, the samples used for experimental studies need to reflect these changes in waste response, which will influence the extent of cuttings release.

Justification

Radioactive release caused by the removal of waste cuttings from the borehole during a human intrusion is currently one of the dominant processes affecting the results of the performance assessment for the disposal regulations. In addition, no direct experimental information currently exists to confirm the waste properties assumed for predictions of cuttings release (Section 5.4.3.2). Instead, assumed erosion properties are taken from the literature for materials, such as clays, that are considered worst-case surrogates of decomposition end products. As a result, the extent of release may be overestimated. Virtually no information is available for examples of borehole spallation. Laboratory tests, therefore, are required to examine waste erosion and spallation processes in order to either support or modify the material property assumptions currently used in cuttings release models.

5.4.3.2 Model of Drill Cuttings

Description

A model is needed for estimating the amount of radioactive cuttings removed from a borehole during penetration of the WIPP repository. During such releases, material adjacent to the borehole wall may be eroded or may spall off into the borehole as the drill penetrates the waste, causing the borehole diameter to become greater than that normally observed in salt-drilling operations. A mathematical method is available for estimating borehole erosion, and is being applied in performance-assessment studies. A description of borehole spallation, however, is still in the development stage and needs to be refined before the impact of spallation on cuttings release can be accessed.

Spallation of materials from the walls of a borehole in any gas-bearing formation may occur when the rock formation is filled with gas, the rock formation permeability is low, and the pressure difference between the gas pressure within the rock formation and the borehole pressure is large. Rapid flow of gas out of the formation into the borehole creates tensile stresses. If these tensile stresses exceed the tensile strength of the rock, spallation occurs. For WIPP, the extent of damage to a borehole drilled into the consolidated waste depends on the permeability of the consolidated waste; the pressure of the gas within the consolidated waste, including how its release might be modified by the presence of adjacent layers of disturbed rock; the mechanical strength of the waste; and the drilling parameters, such as the drilling fluid and the rate of penetration of the drill into the consolidated wastes. A simple model currently exists for estimating of the tensile stress in waste with various assumed waste permeabilities and rates of borehole depressurization, and shows that the faster the drill penetrates, the greater the induced tensile stress in the waste at the borehole wall. This model needs to be expanded to account for a more realistic description of the penetration process and the amount of waste material that may actually be removed by the drilling process. In addition, effective tensile strength of the compacted waste must also be developed.

Justification

Radioactive release resulting from the removal of waste cuttings from a borehole during human intrusion is currently one of the dominant processes affecting the results of the performance assessment for the disposal regulations. Current estimates of release are based entirely on the assumption that erosion dominates cuttings removal; the importance of a second mechanism, spallation of material into the borehole, is currently undefined. Additional development of the spallation model, therefore, is needed, to assess the contribution that this process may have on cuttings release. Additional refinement of the erosion model may be necessary as laboratory test data become available (Section 5.4.3.1).

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Appendices

APPENDIX A
SUMMARY OF DIFFERENCES BETWEEN REVISION 0 AND REVISION 1 OF THE TEST PHASE PLAN

This appendix describes differences between Revision 0 of the *Test Phase Plan for the Waste Isolation Pilot Plant* (formerly *WIPP Test Phase Plan: Performance Assessment*), which was issued in April of 1990, and this current version, Revision 1. The Plan has been updated for several reasons, including the following:

- Revision 0 of the Plan does not address the DOE's program to comply with requirements of the Resource Conservation and Recovery Act. Only plans for compliance with 40 CFR Part 191 were addressed in any detail. The LWA requires that RCRA requirements be included.

- Since 1990, the scientific research and engineering design and development program for the WIPP has progressed and evolved. Revision 1 describes current understanding of outstanding information needs.

- The EPA is required by the LWA to approve the *Test Phase Plan for the Waste Isolation Pilot Plant* only if the Agency determines that the activities described are relevant to a certification of compliance with the final disposal regulations or to compliance with the RCRA. To respond to this requirement and to address comments made by the National Academy of Sciences, Revision 1 has been structured to show relationships between regulatory requirements, associated compliance programs, information needs that must be satisfied to evaluate compliance, and activities to be performed to resolve each information need. Activities are defined as integrated programs of laboratory, field, and modeling studies that collectively define the waste, significant events affecting the disposal system, and natural and engineered barrier systems important to waste isolation. Revision 1 describes these activities and their relevance to certification of compliance with the regulatory requirements. Revision 1 also provides brief descriptions of the individual studies.

Revision 0 provides considerable technical detail in describing the "supporting activities" that are designed to provide information required for the performance assessment. Revision 1 focuses on summarizing the relevance to compliance for the test-phase activities rather than describing details of experiments. Readers interested in comprehensive descriptions of experiments involving waste are referred to *Gas Generation and Disposal Room Source-Term Program: Technical Needs Assessment for the WIPP Test Phase* (DOE, 1992a).

Consistent with the second reason identified above, Revision 1 reflects changes in the test program caused by completion, deletion, or refocusing of certain test phase studies. Table A-1 provides a comparison of currently planned studies with those described in Revision 0. The table includes the Revision 0 activity numbers and titles, Revision 1 study numbers and titles, the study type (laboratory, modeling, field, design, or data base), and the type of change.

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
S.1.1.1	Backfill-Mix Creep and Permeability Behavior	5.2.1.1	Properties of Disposal-Room Backfill	L	Renamed
S.1.1.2	Backfill-Mix Selection Tests	None	None	L	Completed
S.1.1.3	Drum and Box Mechanical Response	5.2.1.2	Mechanical and Permeability Properties of Waste	L	Renamed
S.1.1.4	Laboratory Studies of Repository Chemistry	5.3.1.2	Laboratory Studies of Gas Generation	L	Renamed
S.1.1.5	Radionuclide Chemistry	5.3.2.2	Laboratory Studies of Actinide Source Term	L	Renamed
S.1.2.1	Backfill-Mix Consolidation Model	5.2.1.3	Mechanical Model of Disposal-Room Backfill	M	Renamed
S.1.2.2	Drum and Box Collapse Models	5.2.1.4	Model of Waste Mechanical Properties	M	Renamed
S.1.2.3	Backfill-Mix Selection Analysis	None	None	M	Completed
S.1.2.4	Disposal Room Performance Model	5.2.1.5	Disposal-Room Model and Data Base	M	Renamed
S.1.2.5	Engineered Alternatives	5.2.1.6	Model of Engineered Alternatives	M	No Change
S.1.2.6	Additional Development of EQ3/6	None	None		Terminated
S.1.3.1	Simulated TRU Testing (Rooms T and J)	5.2.1.7	Tests of Simulated Disposal Room (Rooms T and J)	F	Renamed
S.1.3.2	Alcove Gas Generation and Depletion Tests	5.3.4.3 5.3.4.4 5.3.4.5 5.3.4.6	Design of Alcove Test Design and Testing of Alcove Gas-Barrier, -Management, and -Sampling Systems Alcove Test Operations Characterization and Preparation of Alcove Waste	F F F F	Split Into Alcove Activity Components

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Continued)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
S.1.3.3	Bin-Scale Gas Generation and Depletion Tests	5.3.1.3 5.3.2.3	Gas-Generation Experiments (Bin Tests) with CH TRU Waste Large-Scale Studies of the Actinide Source Term with CH TRU Waste	F F	Split into Gas Generation & Actinide Source Term Components
S.2.1.1	Geochemical Stability of Seals Materials	5.2.2.1	Development of Materials for Short-Term Seals	L	Renamed
S.2.1.2	Crushed Salt Consolidation	5.2.2.2	Development of Materials for Crushed-Salt Seals	L	Renamed
S.2.1.3	Cementitious and Earthen Materials Development	5.2.2.1	Development of Materials for Short-Term Seals	L	Combined w/S.2.1.1
S.2.2.1	Crushed Salt Consolidation Modeling	5.2.2.4	Model of Seals Components	M	Renamed
S.2.2.2	Seal System Design, Analysis, and Integration	5.2.3.1	Seal Design and System Model	M	Renamed
S.2.3.1	Small-Scale Seal Performance Tests	5.2.2.6	Small-Scale Tests of Seals Performance	F	No Change
S.2.3.2	Large-Scale Seal Testing	5.2.2.7	Large-Scale Testing of Seals	F	No Change
S.2.3.3	Borehole Plugging	5.2.2.8	Borehole Plugging Tests	F	No Change
S.3.1.1	Stress Generalization; Verification of the Creep Flow Surface	5.2.4.1	Study of Material and Fracture Properties	L	Renamed
S.3.1.2	Transient Strain Limit Determination	5.2.5.1	Distribution Functions for Creep Parameters	L	Renamed
S.3.1.3	Pressure Effect on Fracture Rehealing	5.2.4.3	Kinetics of Fracture Healing in Salt	L	Renamed
S.3.1.4	Moisture Effect on Creep Rate	None	None		Completed
S.3.1.5	Stress, Strain/Brine Transport	5.1.3.8	Model Development for the Salado	M	Renamed

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Continued)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
S.3.2.1	Constitutive Model Development	5.2.5.3	Development of Salt Constitutive Model	M	No Change
S.3.2.2	Numerical Code Development	5.2.5.5	Development of Numerical Code	M	No Change
S.3.2.3	Code Verification and Validation	5.2.5.6	Verification and Validation of Code	M	No Change
S.3.2.4	Brine Inflow Model	5.1.3.8	Model Development for the Salado	M	Combined with S.3.2.1
S.3.2.5	Three-Dimensional Mechanistic Hydrological Transport Model of Facility	5.1.3.7	Repository-Scale Multiphase Modeling and Sensitivity Studies	M	Renamed
S.3.2.6	Integrated Mechanical Model, Disturbed Rock Zone, and Excavation Effects	5.2.4.4	Mechanical Model of Excavation Effects in the Disturbed Rock Zone	M	Renamed
S.3.3.1	Air Intake Shaft Performance	5.2.5.7	Performance of Air Intake Shaft	F	No Change
S.3.3.2	Intermediate-Scale Borehole Test (Room C1)	5.2.5.8	Intermediate-Scale Borehole Test	F	No Change
S.3.3.3	Panel Structural-Response Tests	5.2.5.9	Panel Structural Test	F	No Change
S.3.3.4	Gas Flow/Permeability	None	None		Completed
S.3.3.5	Near-Field Flow Characterization	None	None		Completed
S.3.3.6	Brine Inflow Scale and Stratum Effects	5.1.3.5 5.1.3.9	Salado Brine Chemistry Test Design and Interpretation for the Salado	L M	Split Into Component Studies
S.3.3.7	Pore Pressure for Brine Inflow	5.1.3.13	Small-Scale/Intermediate-Scale Brine-Inflow Experiments	F	Renamed
S.3.3.8	Brine Inflow to Excavated Rooms	5.1.3.14	Large-Scale Brine-Inflow Experiments	F	Renamed

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Continued)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
S.3.3.9	Brine Permeability Testing of the Disposal Horizon	5.1.3.12	Salado Far-Field Permeability Testing	F	Renamed
S.3.3.10	Air Intake Shaft Brine Permeability Testing	None	None		Completed
S.3.3.11	Shaft Geophysics	5.2.4.6	Geophysics of the Disposal System	F	Renamed
S.3.3.12	Underground Geophysics	5.2.4.6	Geophysics of the Disposal System	F	Combined with S.3.3.11
S.3.3.13	Brine Sampling and Evaluation Program	5.1.3.13	Small-Scale/Intermediate-Scale Brine-Inflow Experiments		Combined with S.3.3.7
S.4.1.1	Batch Kd Measurements	5.1.2.4	Empirical Sorption Studies for the Non-Salado	L	Renamed
S.4.1.2	Mechanistic Studies of Sorption	5.1.2.1 5.1.2.2 5.1.2.3	Adsorption Studies for the Non-Salado Radionuclide Solubility and Speciation for the Non-Salado Brine Mixing and Radionuclide Coprecipitation for the Non-Salado	L L L	Split Into Component Studies
S.4.1.3	Solute Column Transport	5.1.2.5 5.1.2.6 5.1.1.3	Column Experiments for the Non-Salado Long Core Tracer Tests for the Non-Salado Model Development for the Non-Salado	L L M	Split Into Component Studies
S.4.1.4	Rustler Radiocarbon	5.1.1.5	Regional Geochemical Studies	L	Renamed
S.4.1.5	Mineralogical and Hydrochemical Studies in Support of Sorption Experiments	None	None		Completed
S.4.2.1	Final Two-Dimensional Culebra Modeling	None	None		Completed
S.4.2.2	Solute Transport-Brine Reservoir Breach Into the Culebra	None	None		Completed

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Continued)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
S.4.2.3	Far-Field Hydrologic Flow and Boundary Conditions	5.1.1.2 5.1.1.3	Regional-Scale Transport and Sensitivity Studies Model Development for the Non-Salado	M M	Split Into Component Studies
S.4.2.4	Far-Field Culebra Transport Mechanisms Under Disturbed and Undisturbed Conditions	None	None		Completed
S.4.3.1	H-11 Multipad/Tracer Test	None	None		Completed
S.4.3.2	Rustler Response to Air Intake Shaft	None	None		Completed
S.4.3.3	Single-Hole Hydraulic Tests of the Rustler Formation	None	None		Completed
S.4.3.4	Single-Pad Interference Tests of the Culebra Dolomite	5.1.1.4	Field Testing and Data Interpretation for Non-Salado Hydrology	F	Renamed
S.4.3.5	Conceptual Hydrogeologic Model of the Rustler Formation	5.1.1.1 5.1.1.2 5.1.1.8	Core Studies of Non-Salado Rock Properties Regional-Scale Transport & Sensitivity Studies Verification of Non-Salado Performance Assessment Model	M M M	Split Into Component Studies
S.4.3.6	Bell Canyon Hydrologic Information	None	None		Completed
S.4.3.7	Dewey Lake Red Beds Hydrology	None	None		Completed
S.4.3.8	Surface Geophysics	None	None		Completed
S.4.3.9	Regional Geochemical Studies: Solute Chemistry and Mineralogy	None	None		Completed
S.4.3.10	Regional Geochemical Studies: Dissolution	None	None		Completed

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Continued)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
S.4.3.11	Regional Geochemical Studies: Paleoclimate	None	None		Completed
None	None	5.1.1.6	Data Base for Non-Salado Field Studies	P	New
None	None	5.1.1.7	Validation and International Collaboration for Non-Salado Model	M	New
None	None	5.1.1.9	Identifying Potential Underground Sources of Drinking Water	L	New
None	None	5.1.2.7	Colloid Characterization and Transport for the Non-Salado	L	New
None	None	5.1.2.8	Test Design and Interpretation for the Non-Salado	M	New
None	None	5.1.2.9	Non-Salado Data Base for Performance Assessment	P	New
None	None	5.1.2.10	Sorbing/Retarding Tracer Tests for the Non-Salado	F	New
None	None	5.1.2.11	Data Base for Non-Salado Laboratory Studies	P	New
None	None	5.1.2.12	Non-Sorbing Tracer Tests for the Non-Salado	F	New
None	None	5.1.3.1	Salado Threshold Pressure	L	New
None	None	5.1.3.2	Salado Relative Permeability	L	New
None	None	5.1.3.3	Salado Permeability Versus Stress	L	New
None	None	5.1.3.4	Salado Porosity	L	New
None	None	5.1.3.6	Data Base for Salado Laboratory Studies	P	New
None	None	5.1.3.10	Validation and International Collaboration for Salado Model	M	New

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Continued)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
None	None	5.1.3.11	Salado Data Base for Performance Assessment	P	New
None	None	5.1.3.15	Threshold-Pressure Testing of Marker Bed 139	F	New
None	None	5.1.3.16	Data Base for Salado Field Studies	P	New
None	None	5.1.3.17	Benchmarking of Mechanistic and Performance-Assessment Models	M	New
None	None	5.1.4.1	Gas Solubility in Salado Brines	L	New
None	None	5.1.4.2	Retardation in the Salado	L	New
None	None	5.1.4.3	Tracer and Transport Testing in the Salado	F	New
None	None	5.1.4.4	RCRA Constituents Retardation in the Salado	L	New
None	See pg. 1-20, paragraph 3, of TPP Rev. 0	5.2.1.8	Feasibility Analysis for Room-Scale Test	F	New
None	None	5.2.2.3	Data Base for Seals Materials	P	New
None	None	5.2.2.5	Sealing System Integration	P	New
None	None	5.2.4.2	Disturbed-Rock-Zone Mechanisms	L	New
None	None	5.2.4.5	Characterization of Disturbed Rock Zone	F	New
None	None	5.2.4.7	Hydrofracture Studies of the Anhydrite Beds	F	New
None	None	5.2.5.2	Validation, Documentation, and QA for the Rock-Mechanics Data Base	P	New
None	None	5.2.5.4	Development of Fracture Constitutive Model	M	New
None	None	5.2.5.10	Test of Thermal and Structural Interaction	F	New
None	None	5.2.5.11	Integration of Rock-Mechanics Studies	P	New

Table A-1. Matrix Comparing Current Test Phase Plan Studies With April 1990 Test Phase Plan Studies (Concluded)

April 1990 Test Phase Plan (Revision 0)		Current Test Phase Plan (Revision 1)		Study Type[1]	Change
Study	Title	Section	Title		
None	None	5.2.5.12	Mine-Support-System Technology and Demonstrations	F	New
None	None	5.3.1.1	Model of Gas Generation	M	New
None	None	5.3.2.1	Model of the Actinide Source Term	M	New
None	None	5.3.3.1	Characterization of the Waste Inventory for the Compliance Source Terms	F	New
None	None	5.3.4.1	Hazardous-Organic-Constituents Degradation Rates and Reaction Products	M	New
None	None	5.3.4.2	Characterization of VOC Transport out of Waste Containers	L/M	New
None	None	5.4.1.1	Culebra Desaturation Resulting from Human Intrusion	M	New
None	None	5.4.2.1	Expert Panels (Probability of Human Intrusion vs. Time)	M	New
None	None	5.4.3.1	Laboratory Studies of Drill Cuttings	L	New
None	None	5.4.3.2	Model of Drill Cuttings	M	New

1. L = Laboratory Study
   M = Modeling Study
   F = Field Study
   D = Design Task
   P = Protocol (data base management, integration of studies, etc.)

APPENDIX B
WIPP PERFORMANCE ASSESSMENT BIBLIOGRAPHY

For the convenience of the reader, the current bibliography for the 40 CFR 191 performance assessment is reproduced here. Two categories of documents are listed: "published" and "in preparation." Published documents are generally available through the National Technical Information Service, US Dept. of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

In addition, many documents pertaining to the WIPP were submitted to the U.S. Environmental Protection Agency in support of its review of the WIPP *No-Migration Variance Petition* for the test phase. These documents are located in the EPA docket for the petition. A listing of the documents located in the docket, and copies of these documents may be reviewed by the public. They are available for review in Room M2427, U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460. An appointment may be made to review these materials by calling (202) 475-9327.

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Glossary

GLOSSARY

TERM	DEFINITION
40 CFR Part 136	This regulation prescribes procedures to be used to perform measurements of the concentrations of waste constituents in samples, when such measurements are required by provisions of the Clean Water Act of 1977.
40 CFR Part 141	This regulation establishes primary drinking water regulations pursuant to the Public Health Service Act, the Safe Drinking Water Act, and related regulations applicable to public water systems.
40 CFR Part 191	This regulation sets environmental radiation protection standards for management (Subpart A) and disposal (Subparts B and C, as proposed) of spent nuclear fuel, high-level and transuranic radioactive wastes.
40 CFR Part 264	This regulation establishes minimum national standards which define the acceptable management of hazardous waste.
40 CFR 264, Subpart X	This regulation specifies requirements that apply to owners and operators of facilities that treat, store, or dispose of hazardous waste in miscellaneous hazardous waste management units.
40 CFR Part 268	This regulation restricts the land disposal of hazardous wastes and specifies treatment standards and/or treatment technologies that must be met or applied before hazardous wastes may be land disposed. Section 268.6 of Part 268 provides for petitioning to allow land disposal of untreated hazardous waste if it can be demonstrated to a reasonable degree of certainty that there will be no migration of hazardous constituents from the disposal unit for as long as the waste remains hazardous.
Actinide Source Term	The fraction of the total radionuclide inventory of a disposal room or repository that can be mobilized for transport to the accessible environment.
Alcove	A specially designed room excavated in the WIPP underground for testing with actual transuranic waste.
Alcove Gas Barrier	A massive seal constructed to meet an acceptable gas leakage rate into or out of an alcove.
Alternative Container Materials	Container materials, other than mild steel, that reduce and/or eliminate gas generation from corrosion in the range of expected WIPP environments.
Backfill	Material placed around the waste containers, filling the open space in the disposal room.
Backpressure	Pressure caused by a force operating in a direction opposite to that being considered, such as that of a pore fluid pressure on matrix rock or the resistance of the waste and backfill to compaction by creep closure of the salt formation surrounding the disposal rooms.

TERM	DEFINITION
Barrier	"[A]ny material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides" (40 CFR 191.12[d]). Barriers also prevent or delay the movement of hazardous constituents.
Bell Canyon Formation	A sequence of rock strata that form the topmost formation of the Delaware Mountain Group (Early Permian).
Benchmark	To compare predictions made with one code with those obtained with other codes or with analytical solutions. Benchmarking is a part of verification.
Bin	A gastight steel box specially designed for tests with transuranic waste in the WIPP.
Borehole	1) A hole drilled from the surface for purposes of geologic or hydrologic testing, or exploration of resources; sometimes referred to as a drillhole. 2) A manmade hole in the wall, floor, or ceiling of a subsurface room used for verifying geology, making observations, or emplacing canisters of remote-handled transuranic (RH-TRU) waste.
Buffered Humid Conditions	Under long-term conditions, the absolute (and relative) humidities within the WIPP are expected to be buffered by the activity of water in adjacent portions of the Salado Formation. The term is also used to refer to a condition created as part of the bin test, to maintain waste at a relative humidity of about 70% by equilibrating the wastes inside the bin with an external source of artificial Salado brine (Brine A).
Computational Model	The computational model is the implementation of the mathematical model. The implementation may be through analytic or numerical means. Often the analytic solution is numerically evaluated (e.g., numerical integration or evaluation of complex functions); hence, both solution techniques are typically coded on the computer. Consequently, the computational model is often called a computer model.
Computer Model	The appropriately coded analytical or numerical solution technique used to solve a mathematical model.
Conceptual Model	The set of hypotheses, generally based on observation, that postulate the description and behavior of a system. This description may include significant structural geometry, material properties, and physical processes that affect behavior.

TERM	DEFINITION
Confirmation	For purposes of this document, a term used to indicate support or establishment of certainty and/or efficiency or validity of models used in reference to specific performance issues of the repository over any specific timeframe of interest. In general, laboratory and field experiments at WIPP and elsewhere are conducted to provide data in support of this type of activity, such as for the gas generation model. Confirmation is used here in a mechanistic sense, and is not intended to have specific legal or code implications (see validation).
Consultation and Cooperation (C&C) Agreement	An agreement that affirms the intent of the Secretary of Energy to consult and cooperate with the State of New Mexico with respect to State public health and safety concerns. The term "Agreement" means the July 1, 1981 Agreement for Consultation and Cooperation, as amended by the November 30, 1984 "First Modification," the August 4, 1987 "Second Modification," and the March 18, 1988 "Third Modification," or as it may be amended after the date of enactment of this Act, between the State and the United States Department of Energy as authorized by section 213(b) of the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Pub. L. 96-164; 93 Stat. 1259, 1265).
Contact-Handled (CH) Waste	TRU waste that has a measured radiation dose rate at the container surface of 200 millirems per hour or less and the filled containers can be safely handled without special equipment when drummed.
Controlled Area	The controlled area means "1) a surface location, to be identified by passive institutional controls, that encompasses no more than 100 square km and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and 2) the subsurface underlying such a surface location" (40 CFR 191.12[g]).
Creep	A very slow, usually continuous, time-dependent movement of soil or rock; refers to the geologic phenomenon experienced as the gradual flow of salt under high compressive loading.
Creep Closure	Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.
Cuttings	Rock chips cut by a bit in the process of drilling a borehole or well.
Decommissioning Phase	The term "decommissioning phase" means the period of time beginning with the end of the disposal phase and ending when all shafts at the WIPP repository have been back-filled and sealed.
Desaturate	To remove liquid from a material to reduce the degree of saturation. If all the liquid is removed from pores and cracks, the material is said to be completely dried.
Disposal	The term "disposal" means permanent isolation of transuranic waste from the accessible environment with no intent of recovery, whether or not such isolation permits the recovery of such waste. Disposal of waste in a mined geologic repository occurs when all the shafts to the repository are backfilled and sealed (40 CFR 191.02[l]).

TERM	DEFINITION
Disposal Facility	A facility or part of a facility into which hazardous waste is intentionally placed and in which hazardous waste will remain after closure.
Disposal Phase	The term "disposal phase" means the period of time during which transuranic waste is being emplaced in the WIPP, beginning with the initial emplacement of transuranic waste underground for disposal and ending when the last container of transuranic waste, as determined by the Secretary of Energy, is emplaced underground for disposal.
Disposal Room	An excavated cavity in the WIPP underground in which transuranic waste will be emplaced if disposal is allowed to begin.
Disposal Room Source Term	Based on projected representative disposal room inventories for the WIPP repository, the disposal room source term includes the potentially mobile fraction of the inventory that could be transported beyond the controlled area to the accessible environment (per 40 CFR 191). The source term may include dissolved, complexed, and colloidally sorbed radionuclides and hazardous waste substances. Some hazardous wastes may also be mobilized as VOCs with gases produced by microbial degradation, corrosion of metals, and radiolysis serving as a carrier.
Disposal System	Any combination of engineered and natural barriers that isolate spent nuclear fuel or radioactive waste after disposal (40 CFR 191.12[a]). The WIPP disposal system comprises the repository/shaft system and controlled area.
Disturbed Rock Zone (DRZ)	That portion of the geologic barrier of which the physical and/or chemical properties may have changed significantly as a result of underground construction activities.
Emplacement	At the WIPP, the placing of radioactive wastes within the repository so as to safely confine them.
Engineered Barriers	Backfill, seals, and any other manmade barrier components of the disposal system.
Environmental Evaluation Group (EEG)	An oversight group, established by the Congress, that performs independent technical evaluation to insure protection of the public health and safety, and the environment.
Flowpath	The path traveled by a neutrally buoyant particle released into a groundwater-flow field.
Gas Generation Model	A computational model that can simulate and/or predict the gas generation rate of TRU wastes in a disposal room of the decommissioned repository.
Gas Generation Rate	The combined gas production rate from all species of gases produced as a result of TRU waste degradation due to corrosion, microbial, and/or radiolytic processes present in the repository at any given time. The rate of production throughout the history of the repository is expected to vary depending on repository conditions with respect to humidity, total or partial brine inundation, competitive reactions that absorb specific gases, and with the ability of the repository to retain the gases being formed. The term is also applied to individual gases.

TERM	DEFINITION
Generator and/or Storage Sites	Refers to the ten DOE sites nationwide where TRU wastes are generated and/or stored as a result of activities associated with nuclear weapons production.
Getters	Substances that sorb gases, such as CO_2, and that can be added with other backfill materials to mitigate the pressure buildup in the repository.
Grout	A mortar or cement slurry (of high water content) used to plug potential fluid-flow paths in geologic or engineered structures.
Hazardous Constituent	Those chemicals identified in Appendix VIII of 40 CFR Part 261.
Hazardous Waste	A hazardous waste as defined in 40 CFR 261.3 (40 CFR 260.10).
Host Rock	The rock unit in which radioactive waste is emplaced.
Human Intrusion	Inadvertent human disruptions of a mined geologic repository that could result in loss of containment of the waste. The most severe disruption would occur through inadvertent or intermittent intrusion by exploratory drilling (into the repository) for resources (40 CFR 191, Appendix B).
Lithostatic Pressure	Subsurface pressure due to the weight of overlying rock or soil.
Long Term	Refers to the 10,000 years after shaft sealing for which performance assessment calculations and models assess the behavior of the repository with respect to compliance with 40 CFR 191 and 40 CFR 268.6.
Migration	In the context of 40 CFR 268.6, "migration" means the movement of hazardous constituents beyond the boundary of a hazardous waste management unit in concentrations exceeding health-based levels.
Miscellaneous Hazardous Waste Management Unit	A waste management unit where hazardous waste is treated, stored, or disposed of and that is not a container, tank, surface impoundment, pile, land treatment unit, landfill, incinerator, boiler, industrial furnace, underground injection well, or unit eligible for a research, development, and demonstration permit (40 CFR 260.10).
Mixed Waste	Mixed waste contains both radioactive and hazardous components, as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.
No-Migration Determination for Test Phase	The term "No-Migration Determination" means the Final Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant published by the Environmental Protection Agency on November 14, 1990 (55 Fed. Reg. 47700), and any amendments thereto, pursuant to the Solid Waste Disposal Act (42 U.S.C. 6901 et seq.).
Performance Assessment	A term used to denote all quantitative activities carried out to 1) evaluate the long-term ability of WIPP to effectively isolate the waste and ensure long-term health and safety of the public by complying with 40 CFR 191 and 40 CFR 268.6, and 2) provide the basis for demonstrating regulatory compliance.
Permeability	In hydrology, the capacity of a rock sediment or soil to transmit fluids.

TERM	DEFINITION
Public Law 96-164	The U.S. Department of Energy National Security and Military Application of Nuclear Energy Act of 1980. Public Law 96-164 directed the DOE to proceed with the design and development of the WIPP.
Public Law 102-579	See WIPP Land Withdrawal Act
RCRA Permit Application	An application which is submitted by the owner/operator of a hazardous waste management unit to the state (if authorized by the EPA) or to the EPA. The application is for a RCRA permit to operate the unit. A RCRA permit application consists of two parts: Part A and Part B.
Real-Time Radiography (RTR)	RTR is a nondestructive, nonintrusive examination technique that enables a qualitative (and in some cases semiquantitative) evaluation of the contents of a waste container. RTR utilizes x-rays to inspect the contents of the waste container and allows the operator to view events in progress (real time). RTR is used to examine and verify the physical form of the waste for certain waste forms, identify individual waste components, and verify the absence of certain noncompliant items, as applicable.
Release	Movement of regulated substances into the accessible environment as defined in 40 CFR 191 or beyond the unit boundary as defined for 40 CFR 268.6.
Remote-Handled (RH) Waste	TRU wastes that have a measured radiation dose rate at the container surface of between 200 millirems per hour and 1000 rem per hour and, therefore, must be shielded with lead for safe handling.
Repository	The portion of the WIPP repository/shaft system within the Salado Formation, including the access drifts, waste panels, and experimental areas, but excluding the shafts.
Repository/Shaft System	The WIPP underground workings, including the shafts, all engineered barriers, and the altered zones within the Salado Formation and overlying units resulting from construction of the underground workings.
Salado Formation	A Permian age sequence of salt with minor amounts of clay and anhydrite. Host rock for the WIPP.
Sludge	Refers to de-watered CH-TRU wastes containing both organic and inorganic constituents that must meet WAC criteria for shipment and disposal at the WIPP repository. High sludges refers to CH-TRU where the sludge component constitutes 50% or more of the waste volume; low sludges are the same type of waste that contains less than 50% by volume of sludge.
Source Term	The kinds and amounts of radionuclides (per 40 CFR Part 191) or hazardous wastes (per 40 CFR Part 268) that can be mobilized for transport.

TERM	DEFINITION
Transuranic Waste (TRU Waste)	The term "transuranic waste" means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for— (A) High-level radioactive waste; (B) Waste that the Secretary has determined, with the concurrence of the Administrator, does not need the degree of isolation required by the disposal regulations; or (C) Waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.
Unit Boundary	The unit boundary for a defense-generated TRU waste geologic repository is that portion of the geologic formation in which waste is emplaced, that falls within the land area controlled by the DOE.
Validation	The process of assuring through sufficient testing of a model using real site data, that a conceptual model and corresponding mathematical and computer models correctly simulate a physical process with sufficient accuracy.
Verification	The process of assuring (e.g., through tests on ideal problems) that a computer code (computational model) correctly performs the stated capabilities (such as solving the mathematical model). Given that a computer code correctly solves the mathematical model, the physical assumptions of the mathematical model must them be checked through validation.
Volatile Organic Compound	Includes all EPA-specified volatile organic compounds that are present in CH TRU waste and that accumulate in the headspace of a drum, bin, or alcove.
Waste Acceptance Criteria (WAC)	A set of conditions established for permitting transuranic wastes to be packaged, shipped, managed, and disposed of at the WIPP facility.
Waste Characterization	Sampling, monitoring, and analysis activities to determine the extent and nature of the waste.
Waste Characterization Program	The processes of CH-TRU waste analysis under the WAC to support the No-Migration Determination, Part B of the RCRA Permit Application, other permits, transportation requirements, and the Test Phase experimental requirements. This analysis includes documentation of process knowledge of waste generation, visual characterization of waste components, RTR analysis, and passive-active neutron waste assay for radionuclide content. Headspace analysis for various gaseous components including VOCs are also part of the characterization program.
WIPP	The term "WIPP" means the Waste Isolation Pilot Plant project authorized under section 213 of the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Pub. L. 96-164; 93 Stat. 1259, 1265) to demonstrate the safe disposal of radioactive waste materials generated by atomic energy defense activities (PL 102-579).

TERM	DEFINITION
WIPP Land Withdrawal Act	Public Law 102-579: withdraws the land at the WIPP site from "entry, appropriation, and disposal," transfers jurisdiction of the land from the Secretary of the Interior to the Secretary of Energy, and reserves the land for activities associated with the development and operation of the WIPP.
Working Agreement	Appendix B of the Agreement of Consultation and Cooperation, which sets for the working details of that Agreement.