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Draft Final Plan For The Waste Isolation Pilot Plant Test Phase: Performance Assessment

December 1989

UNITED STATES DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is responsible for managing the disposition of transuranic (TRU) wastes resulting from nuclear weapons production activities of the United States. These wastes are currently stored nationwide at several of the DOE's waste generating/storage sites. The goal is to eliminate interim waste storage and achieve environmentally and institutionally acceptable permanent disposal of these TRU wastes, much of which is mixed waste, that is, waste that is also contaminated with hazardous substances. The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico is being considered as a disposal facility for these TRU wastes.

The mission of WIPP as established by Congress in 1979 (Public Law 96-164) is to provide "...a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." The fundamental responsibility of WIPP's mission, to demonstrate safe disposal of TRU wastes, is being fulfilled in a phased stepwise approach, leading up to the decision whether to designate WIPP a disposal facility. With the Construction Phase of the WIPP facility nearing completion, WIPP is ready to initiate the next major phase in its development, the Test Phase. The Test Phase period is proposed to collect additional technical data to improve confidence in the prediction of the long-term performance of the repository as required by the applicable environmental regulations (40 CFR 191 and 268).

This document, <u>Draft Final Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment</u> ("the Plan"), is a modification of the draft Test Plan issued by the DOE in April 1989 and includes revisions based on comments from the National Academy of Sciences/National Academy of Engineering (NAS/NAE) WIPP Panel, the U.S. Environmental Protection Agency (EPA), and the Environmental Evaluation Group (EEG). This plan is a living document and will be reassessed and revised periodically based on review comments and the future needs of the Project. It describes the first of the following two major programs to be performed during the Test Phase of WIPP: (1) Performance Assessment - determination of the long-term performance of the WIPP disposal system in accordance with the requirements of the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15; and (2) Operations Demonstration - evaluation of the safety and effectiveness of the DOE TRU waste management system's ability to emplace design throughput quantities of TRU waste in the WIPP underground facility. The Operations Demonstration Program has received external peer review from the Secretary's Blue Ribbon Panel, the Ahearne Committee, the NAS/NAE WIPP Panel, and the EEG. Upon completion of DOE review of these external review comments, the Secretary of Energy will make a decision as to the scope and timing of the Operations Demonstration. Based on the Secretary's decision, the DOE will complete a separate document describing the Operations Demonstration.

The Test Phase is scheduled to begin with the first receipt of waste for gas generation tests as early as July 1990, in accordance with the Secretary's Decision Plan for WIPP, Rev. 0. Prior to initiation of the Test Phase, the following major technical and institutional activities must occur: land withdrawal must be resolved, the Final Safety Analysis Report approved, a Resource Conservation and Recovery Act (RCRA) No-Migration Variance granted, the

Supplement to the Environmental Impact Statement (SEIS) completed and DOE's Record of Decision issued (Decision Plan for WIPP, Rev. 0). Major aspects of WIPP's development have been reviewed by the NAS/NAE WIPP Panel and the EEG. In addition, prior to the initial shipment of waste to WIPP, the DOE and the transportation corridor states will perform many exercises with simulated waste to ensure the system is in place to safely transport and handle the waste. At the conclusion of the Test Phase, the WIPP facility will be evaluated to determine whether it is suitable for permanent disposal of TRU waste. If WIPP is judged to be suitable, the Disposal Phase (an additional 20 years of operation) would then be initiated to demonstrate waste disposal. Only current and future TRU waste meeting the requirements of the WIPP Waste Acceptance Criteria will be accepted for disposal. Assuming that the WIPP repository can be shown to meet all regulatory criteria, it will become the first mined geologic repository for radioactive waste in the United States.

OBJECTIVES OF THE WIPP TEST PHASE

The purpose of the Test Phase is to further the intent of Congress to demonstrate safe and environmentally acceptable disposal of defense wastes and thereby establish a permanent disposal facility for TRU wastes. The activities that will provide the needed information include experiments, analyses, and operations at the WIPP facility. Although the initial part of the Test Phase is well defined, experimental programs will evolve with increasing understanding of the systems under test. The nature, scope, waste quantities, and timing of experiments and full-scale rooms recommended by various groups remain flexible. The sum total of waste for these tests would initially require approximately 2 percent by volume of the design capacity.

The initial plans for the Test Phase described in this document call for the emplacement of approximately 0.5 percent by volume of the design capacity for Phases 1 and 2 of the alcove tests and Phases 1 and 2 of the bin-scale tests. These bin-scale and alcove tests will support assessment of compliance with the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15, and the RCRA Land Disposal Restrictions, 40 CFR 268, Section 6. Additional tests will be defined based on the data acquired during the first two phases of the bin-scale and alcove tests and to incorporate potential engineered alternatives.

In addition, the EPA has requested that the Project monitor the performance of the facility by emplacing waste in two full-scale, instrumented, backfilled, sealed rooms after an appropriate demonstration of retrieval using simulated waste. Waste requirements for these two full-scale room tests would be approximately 1.5 percent by volume of design capacity. The DOE will conduct a feasibility evaluation to determine the best technical approach, scope, and timing of such monitoring. The DOE will consult the NAS/NAE WIPP Panel, the EPA, the State of New Mexico, and the EEG prior to initiation of such tests.

Also, waste requirements for an Operations Demonstration have not yet been determined. As suggested by several reviewers, the DOE will evaluate the operational experience to be gained through the conduct of all of the test activities and will factor this into future decisions on the scope and timing of an Operations Demonstration. Waste emplaced in the WIPP facility during the Test Phase will be retrievable until a decision is made whether WIPP should become a disposal facility. During the Test Phase, per agreement with the State of New Mexico, WIPP will meet the applicable requirements of the EPA Standard, 40 CFR 191, Subpart A.

The two primary objectives of the Test Phase are to demonstrate

1. Reasonable assurance of compliance of the WIPP disposal system (the combination of the repository/shaft system and the controlled area) with the long-term disposal standards of the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15. Compliance of the disposal system will be determined based on a probabilistic performance assessment, incorporating both data and interpretations developed during the Test Phase. The performance assessment will include an evaluation of potential engineered alternatives.

2. The ability of the DOE TRU waste management system (the generating/storage sites, the transportation system, and WIPP) to safely and effectively certify, package, transport, and emplace waste underground at WIPP in accordance with all applicable regulatory requirements. Acceptability of the waste management system will be evaluated by operations testing and monitoring, both individually and collectively, of the elements of the TRU waste management system.

This Plan focuses on the methods and activities required to demonstrate compliance with the long-term performance standard of 40 CFR 191, Subpart B, Sections 13 and 15. In addition, several of the tests planned for the Test Phase will provide data that will be used to support WIPP's demonstration that there will be no migration of hazardous constituents of the waste, as required under the RCRA Land Disposal Restrictions, 40 CFR 268, Section 6.

DESCRIPTION OF TEST PHASE ACTIVITIES

The objectives will be accomplished by completion of two important programs - Performance Assessment and an Operations Demonstration. These two programs, which are described below, will provide the necessary information to determine compliance of the disposal system with applicable environmental requirements and to evaluate the safety and effectiveness of the TRU waste management system operations.

Although Subpart B of 40 CFR 191 was vacated and remanded to the EPA by the U.S. Court of Appeals for the First Circuit, this Plan addresses the Standard as first promulgated. The 1987 Second Modification to the Agreement for Consultation and Cooperation between the DOE and the State of New Mexico (1981) commits the WIPP Project to evaluate compliance with the Standard as first promulgated until a revised standard becomes available. Compliance plans for the WIPP facility will be revised as necessary in response to any changes in the Standard.

<u>PERFORMANCE ASSESSMENT</u> - The performance objective for the WIPP disposal system is to adequately isolate TRU waste from the accessible environment; the performance requirements are reasonable assurance of compliance with the 10,000-year release limits and the 1,000-year dose limits of the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15. The 10,000-year performance assessment will predict cumulative releases of radionuclides to the accessible

environment resulting from both disturbed and undisturbed performance of the disposal system. The 1,000-year assessment will predict annual doses to members of the public in the accessible environment resulting from undisturbed disposal system performance. It will not address the concentration limits established by Subpart B for special sources of ground water, because no such sources exist at WIPP. In evaluating compliance with Subpart B, the guidance provided in Appendix B of the Standard will be followed. To ensure that all plausible responses are identified, scenarios will be developed by coupling the individual events and processes that occur. These scenarios will be screened on the basis of probability, consequence, physical reasonableness, and regulatory interest.

Consequence analysis is used to calculate a performance measure for each of the remaining significant scenarios. The performance measures for the scenarios are normalized, summed, and reported as a "complementary cumulative distribution function" of release probabilities. Uncertainties in the data must be included in calculations of the performance measure for each scenario. To show that WIPP can meet the annual dose limits set for 1,000-year performance, the Standard requires that releases from the undisturbed scenarios be analyzed. If any release to the accessible environment is predicted, transport along biological pathways will be modeled, and doses will be estimated. Uncertainties in the data are included in the dose calculations.

The performance assessment process is divided into five elements: scenario screening; repository/shaft system behavior and performance modeling; controlled area behavior characteristics and performance modeling; computational system development; and consequence analysis. The combined repository/shaft system and controlled area represent the disposal system being assessed.

The performance assessment is scheduled to be completed and a Draft EPA (40 CFR 191) Compliance Report issued by June 1993. Until that time, the Project will use available data, and estimates where data are unavailable, to perform a preliminary consequence analysis and sensitivity analysis every six months, with reports to be issued annually. These annual reports and the Draft Compliance Report will be issued for external peer review by the EPA, the NAS/NAE WIPP Panel, the State of New Mexico, and the EEG. The DOE will meet periodically with the EPA Office of Radiation Programs as the remanded portions of 40 CFR 191 are rewritten, in order to ensure that the WIPP Compliance Approach is consistent with provisions of the new Standard. In addition, there will be periodic briefings to the EPA regarding the Project's compliance with the requirements of RCRA. The Final EPA (40 CFR 191) Compliance Report is scheduled to be issued in June 1994. These target dates are based on current understanding of site performance, current assumptions on waste forms, and existing uncertainties. As new data become available, the schedule may be adjusted accordingly.

<u>Disposal System Characterization Activities</u>

Accurately simulating behavior of the disposal system requires data derived from experiments conducted in the laboratory as well as in the WIPP underground. Such scientific investigations have been conducted since 1975. These studies have resolved many technical issues and have focused attention on aspects still requiring investigation.

There are four major areas of scientific investigation integral to the assessment of disposal system performance. These areas examine the behavior of the disposal room and drift system, the sealing system, structural and fluid-flow behavior of the Salado Formation, and non-Salado hydrology and radionuclide migration. Investigation of these areas involves both laboratory and large-scale underground tests.

Disposal room and drift system activities will examine the interaction of TRU waste and backfill in a waste room. The combined interactions of the source term, waste containers, emplaced backfill and admixtures, brine inflow, and gas generation will be studied through laboratory testing, modeling, and in situ testing. The behavior and performance of possible backfills and additives to be emplaced in access drifts as part of facility decommissioning are also being investigated.

An important parameter of the disposal room and drift system is gas generation. Gaseous products will be generated by microbial and radiolytic decomposition of the TRU waste and corrosion of the waste and waste containers. Gas generation tests with actual TRU waste are required to characterize the behavior of the disposal system under realistic conditions. These tests consist of laboratory tests using radioactive and nonradioactive simulated wastes, three phases of bin-scale tests with CH-TRU waste, and two phases of alcove tests with CH-TRU waste. These tests will provide the data needed to evaluate the effects of gas generated by the waste in realistic environments for both the operational (short-term) period and the postoperational (long-term) period. The information collected in these tests will aid the performance assessment in establishing a sufficient level of confidence in the consequence analysis to demonstrate compliance with the EPA Standard. The waste quantities required for these tests represent approximately 0.5 percent by volume of the WIPP disposal area design capacity. In addition to supporting the Performance Assessment Program, the gas generation tests will provide information to be used to verify the RCRA No-Migration Variance Petition's demonstration that the hazardous constituents will not migrate.

Sealing system activities will examine seal design, system behavior, and overall seal performance. Seals will be developed for use in drifts to isolate waste panels, in access shafts to isolate the repository from the accessible environment, and in exploratory boreholes. Laboratory and in situ tests will evaluate behavior of potential seal materials such as crushed salt, salt/clay mixtures, and concretes. The effect of hazardous contituents of the waste on permanent seal components will also be tested.

Studies of structural and fluid-flow behavior of the Salado Formation will improve the capability to model fluid flow, hydrologic transport, waste room and drift response, and shaft closure. Healing of fractures in the disturbed zone outside excavations and around seals in shafts and access drifts will be evaluated. Effects of brine on salt creep will be examined. Laboratory and in situ tests will provide data for improving models of excavation closure, fracture behavior, permeability, and fluid-flow characteristics of the Salado Formation, and brine inflow to excavated rooms. A wide range of studies will address the behavior of penetrations through the Salado Formation, openings at the repository level, and fluid flow to and through these disturbances in the host rock.

The non-Salado hydrology and radionuclide migration activities will address transport of waste to the Rustler Formation and in the Rustler Formation under present and future conditions. Laboratory studies of sorption and retardation in the Rustler Formation are included, as well as in situ geophysical and hydrological tests from the surface.

In conjunction with the performance assessment, potential engineered alternatives to the current waste disposal system design will be examined. This examination will prepare the Project to implement any necessary changes to the design in a timely manner as a contingency if performance assessment results have a high degree of uncertainty or are unsatisfactory, or if changes are required to enhance the demonstration of no migration as required under RCRA. Examples of alternatives under consideration are waste processing, changes in the storage room or panel configuration, and passive markers. Engineered alternatives will be screened for relative effectiveness using a design analysis model, and will be screened for feasibility with respect to cost, state of technology, regulatory concerns, and worker exposure. The bin-scale tests, which will use actual TRU waste underground at WIPP, are scheduled in three phases. Engineered alternatives that pass initial screening will be tested in Phase 3, and if identified early enough, in Phases 1 and 2. Alternatives that seem effective and feasible will then be evaluated using the formal performance assessment process to quantify the improvement in disposal system performance.

The quality assurance requirements for the Test Phase are defined in a Quality Assurance Program that complies with the basic requirements and applicable supplements of ANSI/ASME NQA-1-1986 (QA Program Requirements for Nuclear Facilities), DOE Order 5700.6B, DOE AL Order 5700.6B (General Operations Quality Assurance), Chapter 11 (Quality Assurance) of the WIPP Final Safety Analysis Report, WIPP DOE 87-007 QA Operations Program, WIPP Project Office Management Directives, and the Sandia National Laboratories Quality Plan and Organization 6000 QA Policy. All activities associated with the performance assessment experiments, from design, implementation, and data collection through analysis and reporting, as well as all performance assessment activities, will comply with the requirements of the Quality Assurance Program.

OPERATIONS DEMONSTRATION - The purpose of the Operations Demonstration Program is to demonstrate safe and effective emplacement of certified waste at the WIPP facility. A separate document will be developed to describe the Operations Demonstration following the Secretary of Energy's decision as to the scope and timing of the program. Key elements of the Operations Demonstration will be waste certification and packaging at the generating/storage sites, the operation of the transportation system, and operation of the WIPP facility. This demonstration will be integrated to include all elements of the TRU waste management system and will require both CH- and RH-TRU waste operations. Operational data needs include results from the evaluation of the safety, environmental adequacy, and effectiveness of operations that will certify, transport, and emplace waste at the WIPP facility. In addition, operational data will be derived from the experience gained during mock demonstrations of bin and drum emplacement and retrieval and the emplacement of actual TRU waste for bin-scale and alcove tests underground at WIPP. The goal of the Operations Demonstration is to provide assurance that operations can be conducted within the limits of all applicable regulatory, technical, industrial, and managerial criteria.

SUMMARY

The Test Phase will begin as early as July 1990 with the receipt of CH-TRU waste for bin-scale and alcove gas generation tests, in accordance with the Secretary of Energy's Decision Plan for WIPP, Rev. 0. Current plans call for 0.5 percent by volume of the waste disposal capacity of WIPP to be emplaced for these experiments. The need is being evaluated for further bin-scale experiments, for the two full-scale rooms requested by the EPA, and for the Operations Demonstration, each of which would require additional waste.

There are two primary programs to be performed during the Test Phase: Performance Assessment and Operations Demonstration. This Plan addresses only the Performance Assessment Program, which consists of a large number of activities, including data collection, modeling, and calculations leading to a performance assessment. These calculations will show whether WIPP can demonstrate reasonable assurance that it is in compliance with Subpart B of 40 CFR 191, Sections 13 and 15; they will take into consideration the effects of engineered alternatives that could be implemented if performance assessment results are otherwise unsatisfactory. In addition, the Test Phase will provide data to verify WIPP's demonstration that hazardous constituents will not migrate as required under 40 CFR 268, Section 6. Annual consequence analysis reports will be issued to demonstrate the Project's progress toward compliance with these regulations. Following issuance of the Final EPA (40 CFR 191) Compliance Report scheduled for June 1994 and an evaluation of WIPP's ability to comply with all applicable environmental regulations, the decision whether to designate WIPP a repository is scheduled to be made in June 1995.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has the responsibility to plan, develop, and implement a long-term defense transuranic (TRU) waste management program. The program must be technically feasible and effective, and environmentally and institutionally acceptable. TRU waste generated from nuclear weapons production activities is currently stored at several DOE waste generating/storage sites. The DOE's goal is to end interim storage and achieve permanent disposal of TRU waste. The primary components of the DOE TRU waste management system are the TRU waste generating/storage sites, a transportation system, and the Waste Isolation Pilot Plant (WIPP), a first-of-a-kind facility to demonstrate deep geologic disposal. Figure 1-1 shows the location of the TRU waste generating/storage sites and the WIPP site.

In 1979, Congress passed authorizing legislation for WIPP and established its mission in Public Law (PL) 96-164:

> "...the WIPP is authorized as a defense activity of the Department of Energy, administered by the Assistant Secretary of Energy for Defense Programs, for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission."

The Final Environmental Impact Statement (FEIS; DOE, 1980) for the WIPP Project was completed in October 1980. Subsequently, a Record of Decision was published on January 28, 1981, to proceed with WIPP, pursuant to regulations of the Council on Environmental Quality for implementation of the National Environmental Policy Act. The Record of Decision concluded that the benefits of proceeding with the WIPP Project, when weighed against its potential environmental impacts and costs, and after considering the benefits, impacts, and costs of reasonable available alternatives, merited proceeding with the phased construction and operation of WIPP. In late 1988, the DOE made a decision to update the WIPP Environmental Impact Statement. A draft Supplement to the Environmental Impact Statement (SEIS) was issued in April 1989 (DOE, 1989b). Following an extended public comment and review period, the final SEIS will be issued in January 1990, and a Record of Decision published in February 1990.

The fundamental responsibility of the mission, to demonstrate safe disposal in compliance with relevant environmental regulatory requirements, is being fulfilled using a stepwise, phased approach. Figure 1-2 is a flow diagram illustrating the development of WIPP through several decision points leading to a decision whether to designate WIPP a disposal facility for TRU waste. The facility is now in transition from the Construction Phase to the Test Phase. Before the Test Phase can be initiated, several major technical and institutional activities (Decision Plan for WIPP, Rev. 0; DOE, 1989a) must be accomplished, including land withdrawal, either administrative or legislative, a Final Safety Analysis Report for the facility approved, a Resource Conservation and Recovery Act (RCRA) No-Migration Variance granted by the U.S. Environmental Protection Agency (EPA), the SEIS completed, and DOE's Record of Decision issued.

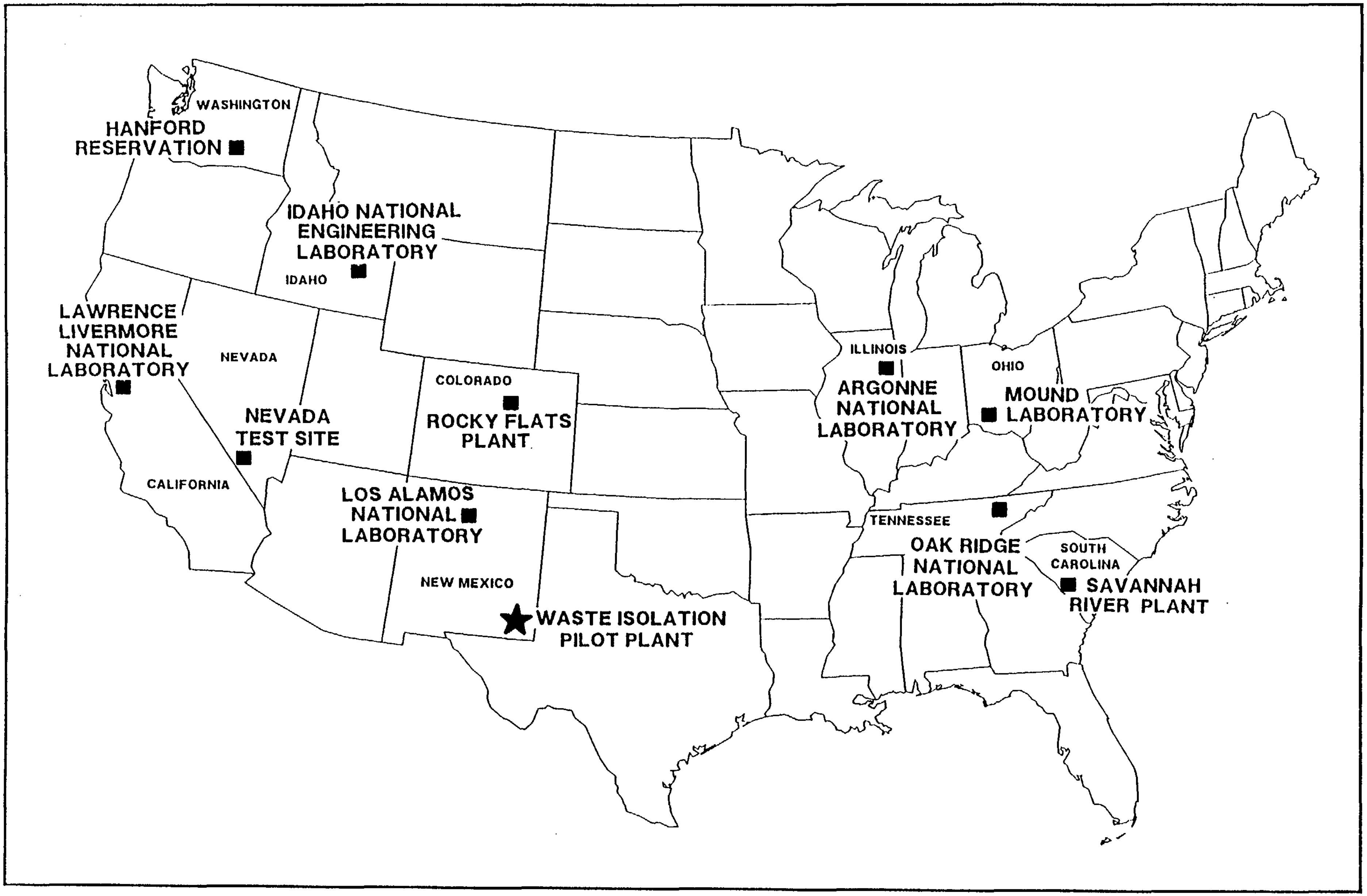


Figure 1-1. Location of WIPP and the Waste Generating/Storage Sites

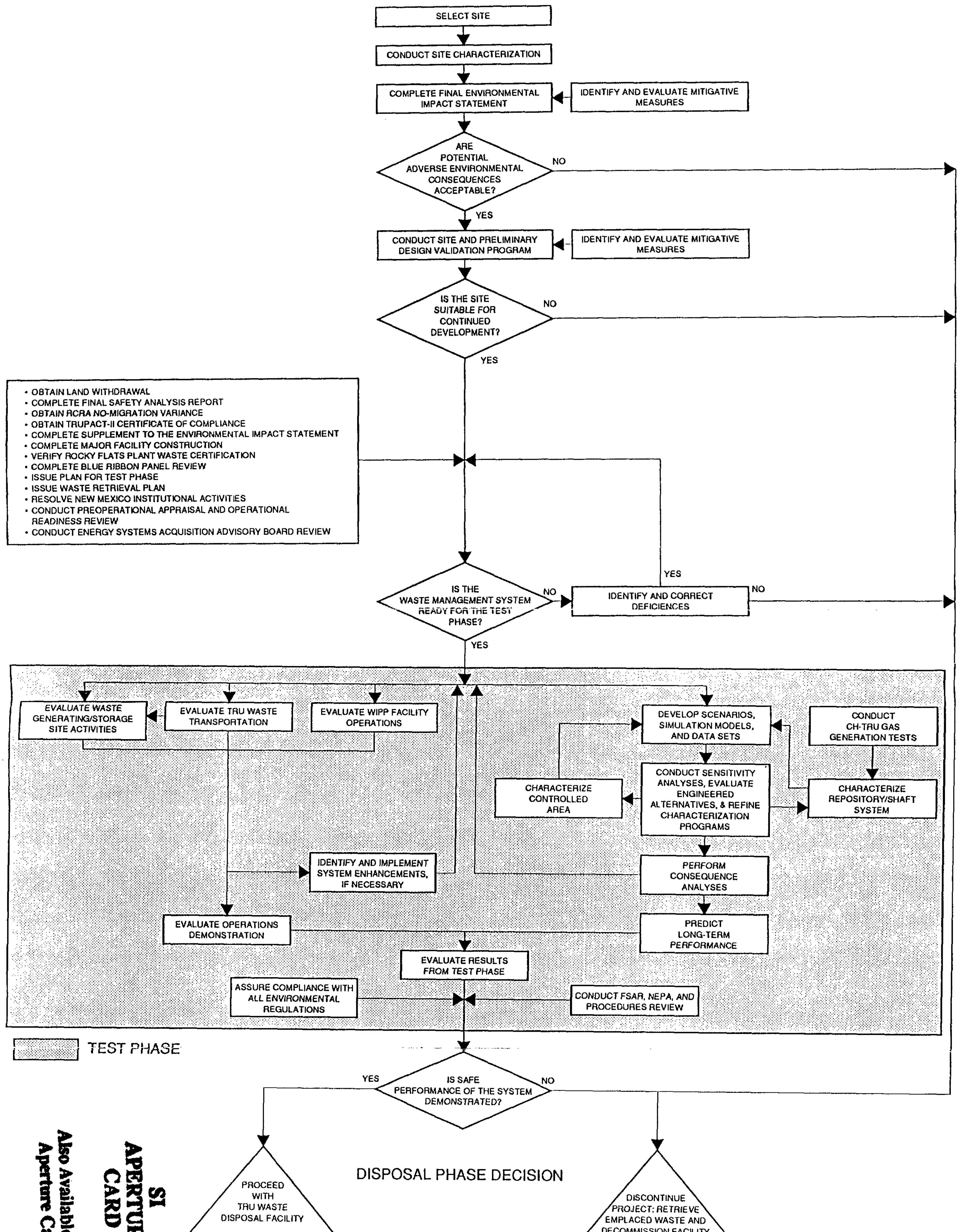


Figure 1-2. Flow Diagram of WIPP Development from Site Selection to the Disposal Phase Decision

During the Test Phase, the WIPP facility will be utilized to perform radioactive and nonradioactive experiments to evaluate the technical and operational aspects of environmentally acceptable disposal of defense-generated TRU waste. The information gathered during the Test Phase will support a determination of compliance with the two primary environmental regulatory requirements governing disposal of radioactive and hazardous wastes: 40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes ("the EPA Standard"; EPA, 1985), and 40 CFR 268, Land Disposal Restrictions.

The EPA Standard, 40 CFR 191, is divided into two subparts which limit radiation and cumulative releases. The first, Subpart A - Environmental Standards for Management and Storage, applies to a disposal facility before decommissioning; the second, Subpart B - Environmental Standards for Disposal, for the most part, applies after decommissioning. Because WIPP will not be a disposal facility during the Test Phase, Subpart A technically does not apply to the Test Phase. However, pursuant to agreements with the State of New Mexico, the facility will operate in compliance with the requirements of 40 CFR 191, Subpart A, beginning with the initial receipt of waste. Subpart A requires that the facility be operated in a manner that provides reasonable assurance that the combined annual radiation doses to members of the public from waste management and storage operations do not exceed 25 mrem to the whole body and 75 mrem to any critical organs. Prior to being designated a permanent disposal facility for TRU waste, the facility must be able to demonstrate compliance with Subpart B of 40 CFR 191. Sections 13 and 15 include a performance assessment and other demonstrations of the ability of the facility to meet certain radiological limits for 1,000 years and 10,000 years after disposal.

WIPP is designed for disposal of certified contact-handled (CH) and remotely handled (RH) TRU waste. Approximately 60 percent of the TRU waste to be disposed of at WIPP is mixed waste; that is, in addition to being radioactively contaminated, it contains materials classified as hazardous and is thus subject to the land disposal restrictions under RCRA. Using the specific criteria identified in 40 CFR 268, Section 6, the DOE has submitted a petition to the EPA demonstrating that there will be no migration of hazardous constituents from the repository for as long as the waste remains hazardous. The EPA's approval of a No-Migration Variance for WIPP will allow the facility to accept wastes otherwise prohibited or restricted from land disposal.

At the conclusion of the Test Phase, information acquired during this period, in conjunction with data collected earlier, will be evaluated to determine whether the WIPP facility is suitable to be a disposal facility for TRU waste. If WIPP is judged to be suitable, the Disposal Phase (an additional 20 years of operation) would then be initiated to demonstrate disposal of current and future TRU waste that meets the WIPP Waste Acceptance Criteria (DOE, 1989c), which were developed to certify that only waste with characteristics within certain bounding limits will be handled and emplaced in the WIPP facility. At the conclusion of the Disposal Phase, the WIPP site would be decommissioned in a way that would allow the safe, permanent disposition of surface and underground facilities consistent with the applicable regulations.

The Test Phase could be initiated as early as July 1990 in accordance with the Secretary's Decision Plan for WIPP, Rev. 0, with the receipt of TRU waste at WIPP for gas generation tests. Current plans call for approximately 0.5 percent of the WIPP disposal area design capacity of CH-TRU waste to be emplaced in Panels 1 and 2 of the WIPP underground facility for these tests. Chapter 2 and Appendix A of this document provide the rationale for the CH-TRU waste tests and information on the quantities and types of waste currently planned to be used. However, the DOE is evaluating additional bin-scale tests associated with the engineered alternatives study (discussed in Activity S.1.2.5), a request by the EPA to instrument and seal two full-scale rooms of waste, and the Operations Demonstration, each of which would require additional quantities of waste. All waste emplaced during the Test Phase will be readily retrievable.

This document, Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment ("the Plan"), is a living document and will be reassessed and revised periodically based on review comments and the future needs of the Project. It identifies and describes the first of the following two key programs to be completed during the Test Phase: Performance Assessment and Operations Demonstration. The Performance Assessment Program will assess the long-term performance of the WIPP disposal system in accordance with the requirements of the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15. Many of the activities to be carried out for the Performance Assessment Program will also collect data that will be used to verify WIPP's demonstration that hazardous constituents of the waste will not migrate, in accordance with the RCRA Land Disposal Restrictions, 40 CFR 268, Section 6. The Operations Demonstration will evaluate the safety and effectiveness of the TRU waste management system's ability to emplace design throughput quantities of TRU waste in the underground facility. The Operations Demonstration Program has received external peer review from the Secretary's Blue Ribbon Panel, the Ahearne Committee, the National Academy of Sciences/National Academy Engineering (NAS/NAE) WIPP Panel, and the Environmental Evaluation Group (EEG). Upon completion of DOE review of these external review comments, the Secretary of Energy will make a decision as to the scope and timing of the Operations Demonstration Program. Based on this decision, the DOE will complete a separate document describing the Operations Demonstration.

This Plan is a programmatic document which provides an appropriate framework for achievement of the objectives of the Performance Assessment Program. Planned activities are clearly delineated and integrated, but not detailed to the level of daily administration. Test plans have been, or will be, prepared to provide further levels of detail. Other subjects, such as quality assurance and safety, are mentioned but not discussed in detail in this Plan; however, each is thoroughly discussed in appropriate Project documents.

1.1 TRU WASTE MANAGEMENT SYSTEM

For the purposes of this Plan, the DOE TRU waste management system consists of three components: the waste generating/storage sites, the transportation system, and the WIPP facility. Each is briefly discussed in this section. In addition, this section contains a brief summary of the WIPP Project development.

1.1.1 Generating/Storage Sites Description

There are ten generating/storage sites (Figure 1-1) within the DOE TRU waste management system. The primary sites shipping experimental waste for the Test Phase will be the Idaho National Engineering Laboratory, which will ship stored CH-TRU waste, and the Rocky Flats Plant, which will provide newly generated CH-TRU waste. Other sites may also ship waste during this period.

Each site that will ship waste to the WIPP facility must meet the requirements of the National Environmental Policy Act and the WIPP Waste Acceptance Criteria. The sites are authorized to implement certification procedures which, together with records generated by the certification process and periodic audits, provide documented evidence and assurance that only waste meeting the Waste Acceptance Criteria will be shipped to the WIPP facility. Transportation of TRU waste to the WIPP facility in TRUPACT-IIs requires that all generating/storage sites meet the requirements of the TRUPACT-II Certificate of Compliance, Safety Analysis Report for Packaging, and the TRUPACT-II Authorized Method for Payload Control. To control these additional shipping requirements, the shippers are preparing implementation plans, similar to those required for waste certification.

1.1.2 Transportation System Description

The transportation system to be employed for shipment of TRU waste to the WIPP facility from the generating/storage sites is highly visible, and has received considerable public attention in recent years due to the potential for transportation-related accidents. However, the safety record associated with transport of radioactive materials has been excellent (Stoller Corporation, 1989; Office of Technology Assessment, 1986). In addition, prior to initial shipment of waste to WIPP, the DOE and the transportation corridor states will perform many exercises with simulated waste to ensure the system is in place to safety transport and handle the waste.

New shipping containers have been designed, built, and licensed specifically for transport of TRU waste. CH-TRU waste drums and boxes will be shipped in TRUPACT-II shipping containers, and RH-TRU waste will be shipped in RH-TRU waste shipping casks. These shipping containers meet Department of Transportation Type B packaging requirements (49 CFR 173); the TRUPACT-II shipping container has been and the RH-TRU waste shipping cask will be certified by the Nuclear Regulatory Commission for safe transportation of nuclear materials. The Standard Waste Box and 55-gallon drums have been certified to Department of Transportation requirements as a Type A container. A TRUPACT-II shipping container will hold 14 drums (two 7-packs) or two Standard Waste Boxes of waste.

The transportation system will use the satellite-based tracking TRANSportation COMmunication System (TRANSCOM) to monitor shipments during transit to and from the WIPP site. Access to tracking information will be made available to the officials in New Mexico, other corridor states, and to Indian Tribes/Pueblos requesting such access. Emergency response training is being provided to emergency responders and officials in New Mexico, other corridor states, and Indian Tribes/Pueblos.

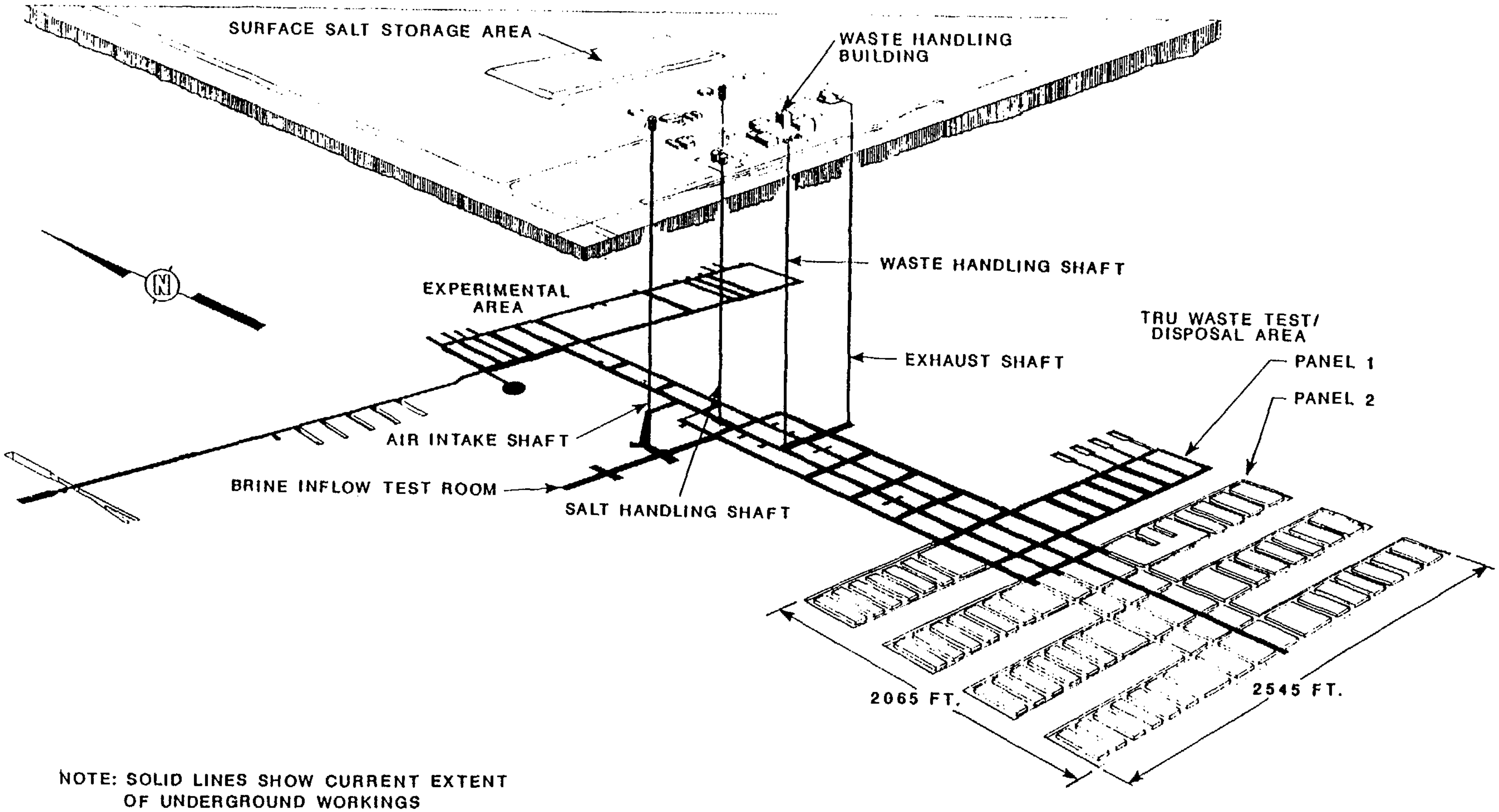


Figure 1-3. The Waste Isolation Pilot Plant

1.1.3 WIPP Description

The WIPP site is located in southeastern New Mexico, approximately 26 mi (42 km) southeast of Carlsbad (Figure 1-1). CH- and RH-TRU wastes differ in the radiation dose rate at the package surface. The CH-TRU waste has radiation dose rates at the package surface below 200 millirem per hour (mrem/hr); the RH-TRU waste package surface dose rates exceed 200 mrem/hr. The TRU waste to be shipped to WIPP is typically comprised of discarded material from defense weapons production and related processes. The waste typically includes a wide variety of materials, such as glassware, metal pipes and tools, disposable laboratory clothing, cleaning rags, and solidified sludges, all contaminated with TRU elements, and the majority are hazardous mixed wastes as defined by RCRA. Much of the CH-TRU waste is packaged in 55-gallon (208-liter) metal drums; in the future, Standard Waste Boxes will be the primary package for the TRU waste. Some waste is presently stored in large metal boxes whose disposition will be evaluated at a later date. The average surface dose rate (≤14 mrem/h) from the CH-TRU waste drums and boxes, which constitute 97 percent of the waste scheduled to be shipped to the WIPP facility, is such that workers may handle the containers without any special shielding precautions. Only 3 percent of the waste drums (RH-TRU) must be remotely handled; these drums will be packaged in steel canisters for remote handling and in specially shielded casks for transportation.

The WIPP facility consists of both surface and underground facilities, including the Waste Handling Building, an Exhaust Filter Building, a Security Building with a visitor center, an Emergency Services Building, a TRUPACT-II maintenance facility, various other support buildings, four shafts to the underground area, underground workings at a single level for waste tests and disposal, and underground maintenance shops (Figure 1-3).

The Waste Handling Building is equipped to handle CH- and RH-TRU wastes in separate areas. The CH-TRU waste area includes shipping and receiving, inspection and inventory, preparation, and an overpack and repair room for damaged containers. The RH-TRU waste area includes shipping and receiving, shipping cask preparation and decontamination, cask loading and unloading, and a hot cell above the loading area for waste canister storage, overpacking, decontamination, and transfer. Although the primary purpose of the Waste Handling Building is to handle TRU waste for emplacement, it is also equipped to handle any TRU waste that must be retrieved. Two independent airlocks at the shaft entrance allow wastes to enter from either the CH- or the RH-TRU waste areas. High efficiency particulate air filtration equipment is utilized in all radioactive materials areas of the Waste Handling Building.

The underground facility is located about 2,150 ft (655 m) below the land surface in the bedded salt (halite) of the Salado Formation. The Salado Formation is approximately 2,000 ft (600 m) thick and 225 million years old. The underground facility is at one mined level and designed in a conventional "room-and-pillar" arrangement. It includes three separate mined areas: a test/disposal area for CH- and RH-TRU wastes; an experimental area dedicated to research and development in rock mechanics, seal design, and facility design; and a shaft pillar area that connects the waste test/disposal, shaft, and experimental areas. The typical disposal rooms are 13 ft (4 m) high, 33 ft (10 m) wide, and 300 ft (91 m) in length; each is separated from the next by 100-ft (30-m) wide pillars of rock salt. Ultimately, eight panels of seven rooms each will be mined. The underground areas are excavated using continuous mining machines. The mined salt is then transported via underground haulage vehicles to a surge bin at the Salt Handling Shaft for removal from the mine.

For final disposal, CH-TRU waste drums and boxes will be stacked in the waste disposal rooms and covered with backfill. RH-TRU waste canisters will be emplaced in horizontal boreholes drilled into the walls of the rooms. The capacity of the WIPP disposal facility is 6,200,000 cubic feet of CH-TRU waste and 250,000 cubic feet of RH-TRU waste.

1.1.4 WIPP Project Development

Since PL 96-164 was enacted establishing the mission of the WIPP Project, program activities have focused on completion of major segments or phases of the Project, thereby allowing significant progress to be made toward demonstrating the safety of WIPP. Each major phase has provided an opportunity to study and evaluate the most recent information, individually and collectively, prior to proceeding with the next phase. Strong influences on the development of the WIPP Project have been the adherence to DOE Order 4700.1 (and its predecessor) regarding "Major System Acquisition" for DOE construction projects, the Consultation and Cooperation Agreement with the State of New Mexico, applicable EPA regulations, and interaction with the NAS/NAE WIPP Panel. The following summary of progress for the WIPP Project illustrates the extent of information collected to date and clarifies the readiness of the Project to enter the Test Phase.

The major phases of the WIPP Project and their relationship to the Key Decisions required in DOE Order 4700.1 are illustrated in Figure 1-4. Key Decision 1 in October 1979 was based upon preliminary site characterization and conceptual design and marked the beginning of the Preliminary Design (Title I). Key Decision 2 in September 1981, to initiate Detail Design (Title II), was made after evaluation of the preliminary design and the 1981 Record of Decision to proceed with the WIPP Project. Key Decision 3 occurred in July 1983 and was based on the successful conclusion of the Site and Preliminary Design Validation Program. This decision initiated the Construction Phase. Key Decision 4, the last decision in terms of DOE Order 4700.1, will be the decision whether the construction phase is complete. This decision would be made after the capability to meet technical performance goals approved in the Project baseline and operational readiness have been demonstrated. Before Key Decision 4 can be made, the following activities must be complete: the Final Safety Analysis Report must be approved, the Preoperational Appraisal and Operational Readiness Review approved, and the SEIS completed and the Record of Decision issued. Two other activities, key to the decision, are already complete: the TRUPACT-II Certificate of Compliance and the completion of major facility construction. The decision is the responsibility of the Energy Systems Acquisition Advisory Board and is expected to be made as early as April 1990 (Decision Plan for WIPP, Rev. 0).

Numerous activities were completed to provide the basis for the Key Decisions described above. Investigation of the geographic area proposed for WIPP, the Los Medanos region of southeastern New Mexico, began in 1972 with a careful review of the extensive geologic data base developed by potash and hydrocarbon industry exploration in the area. The results of this review were favorable, and detailed characterization of the present site was initiated in 1976 with

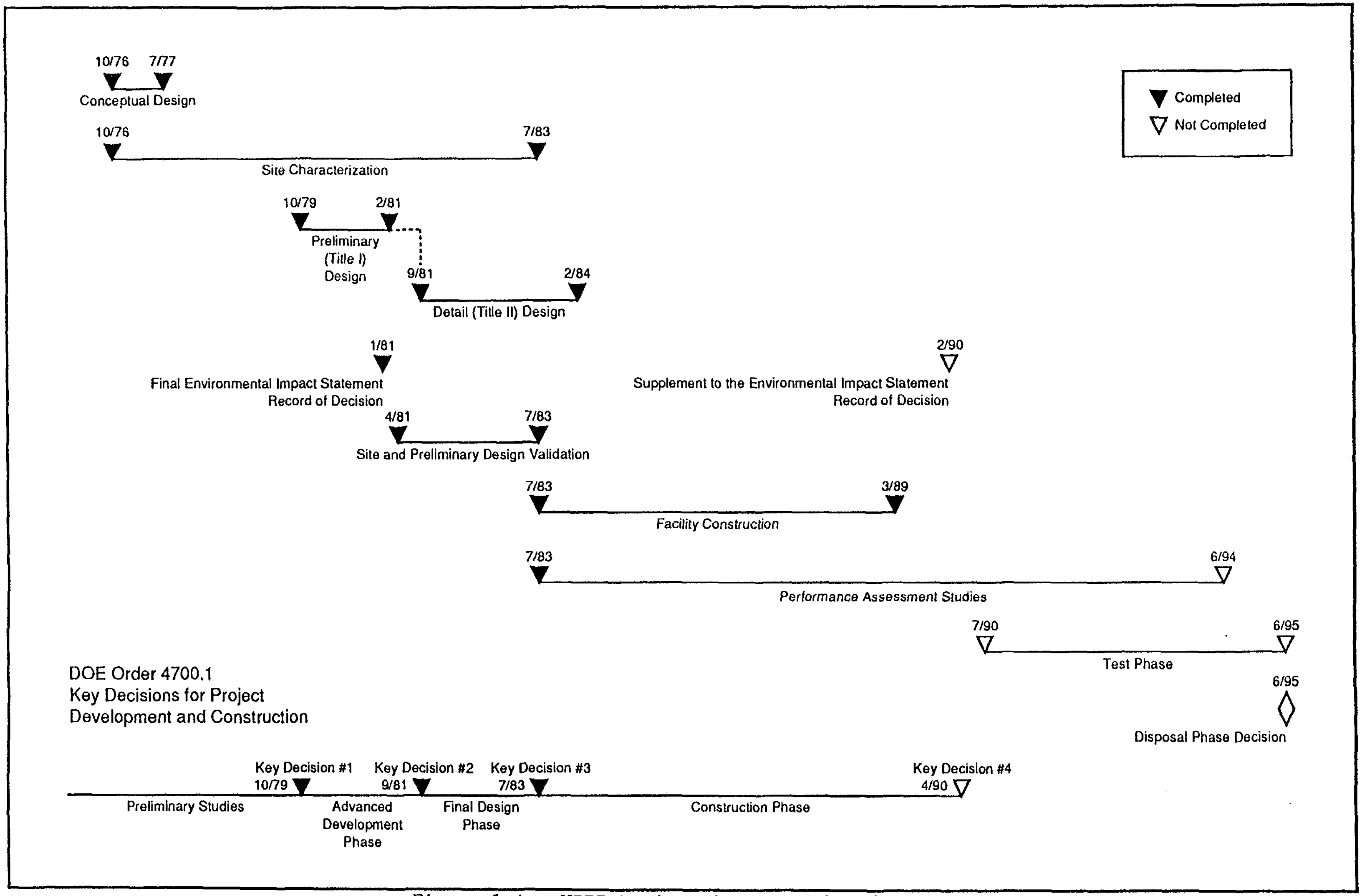


Figure 1-4. WIPP Project Summary Schedule

drilling of a stratigraphic borehole, ERDA-9, at the center of the site. Between 1975 and 1988, over 95 boreholes were drilled and over 35,000 feet of core were retrieved specifically for geologic evaluation of the site. More than 40 of these WIPP boreholes have been used to acquire hydrologic data needed to establish models of local and regional hydrology. In addition, a variety of geophysical exploration techniques, including electrical resistivity, seismic reflection, gravity, and magnetic surveys, have contributed to understanding the site geology (Lappin, 1988).

A comprehensive WIPP research and development program began in 1975 with investigations of salt creep properties and constitutive laws, gas generation from the degradation of TRU waste, corrosion behavior of TRU waste containers, and backfill behavior. From 1981 through 1983, field tests were conducted on waste package materials, large-scale salt deformation, and brine transport in a potash mine near the WIPP site. Investigations in the WIPP underground began in 1982 with the instrumentation of the Salt Handling Shaft and selected underground drifts. An extensive underground (in situ) test program for thermal/structural interactions, plugging and sealing, brine inflow, and waste package performance began in 1983 and is still in progress (Tyler et al., 1988).

In April 1979, the draft Environmental Impact Statement was issued for public comment. These comments were considered and responses made prior to issuing the Final Environmental Impact Statement in October 1980. A Record of Decision was published on January 28, 1981, to proceed with WIPP. Following issuance of the Record of Decision, development and construction of the WIPP facility was initiated. Construction was accomplished in two distinct phases: (1) the Site and Preliminary Design Validation (SPDV) Program, and (2) Facility Construction.

The SPDV Program (1981-1983) was developed and implemented consistent with the Record of Decision to permit direct observation of geologic conditions at the proposed repository horizon and to allow determination of the geomechanical response of the salt beds after excavation of underground workings. Two shafts were drilled, and a four-room test panel was excavated at the selected disposal depth. Extensive data from geologic investigations showed the geology of the disposal horizon to be consistent with predictions based on previous investigations and as described in the FEIS (DOE, 1980). SPDV Program results (DOE, 1983) were made available for review by the State of New Mexico and the public. The results were also presented to the NAS/NAE WIPP Panel, which concluded that a repository meeting the geologic criteria for site selection could be constructed at the WIPP site (NAS, 1983). Based upon the SPDV data and in consideration of comments from all program reviewers, it was concluded that a sound basis had been established to proceed with facility construction.

In concert with the technical activities conducted during the SPDV phase, WIPP was engaged in a comprehensive institutional program. Most significant among the institutional efforts were those which culminated in formal agreements with the State of New Mexico. Several State oversight groups were formed during the late 1970s. The EEG was established to provide independent technical review of safety and environmental aspects of the WIPP Project. An Interim Legislative Radioactive Materials Committee, now known as the Radioactive and Hazardous Materials Committee, consisting of New Mexico legislators, was formed to provide the State with legislative oversight. The Executive Branch convened a a Radioactive Waste Consultation Task Force, comprised of cabinet-level members, to provide input and advice to the Governor. The EEG has provided continuous independent technical oversight of environmental, health, and safety aspects of the WIPP Project by reviewing geologic, hydrologic, environmental/ecological, and engineering studies and reports concerning the Project. The Environmental Evaluation Group has also conducted independent studies and prepared formal reports of their evaluations. In addition, the State of New Mexico has applied to the EPA to obtain Authorization to regulate mixed waste. Upon gaining approval, which is expected to occur in early 1990, the New Mexico Environmental Improvement Division will have responsibility for administering the RCRA mixed waste program, the New Mexico Hazardous Waste Act, and all other applicable state environmental laws and regulations.

In addition to the open communication with these State organizations, the DOE entered into both a Stipulated Agreement and a Consultation and Cooperation Agreement with the State of New Mexico in 1981. The Stipulated Agreement identified geotechnical work to be performed to resolve certain State concerns. The Consultation and Cooperation Agreement defined the process and procedures for consultation and cooperation between the DOE and the State of New Mexico. The geotechnical studies included as part of the original Stipulated Agreement were completed during the SPDV phase. In December 1982, the DOE and the State of New Mexico entered into a Supplemental Stipulated Agreement which included additional geotechnical studies, environmental monitoring, transportation monitoring, emergency response activities, road upgrading, and State liability issues. The Consultation and Cooperation Agreement has been modified several times since its inception. Discussions have also been conducted with representatives from corridor states and Indian reservations through which TRU waste shipments to WIPP are planned. These discussions included such subjects as routing, emergency response, and notification of shipments.

The WIPP Construction Phase (1983-1990) has encompassed all major surface facilities, two additional shafts leading to the underground, excavation and outfitting of the underground experimental areas, and excavation of Panel 1 and associated drifts (Figure 1-3). During the Construction Phase, a formal construction acceptance program was implemented, which required walk-throughs to compare design drawings and specifications to actual construction, system and subsystem testing and certifications to demonstrate that systems were constructed as designed, and as-built drawings. A subsequent start-up program evaluated all the identified critical operating systems, including the Waste Handling and Exhaust Filter Buildings, the shaft and hoisting systems, the CH-TRU waste handling system and equipment, all monitoring systems, controls and instrumentation, utilities (electrical, water, and fire protection), and the underground ventilation system. This process of systematic testing and audits of the construction systems and facilities, which is nearly complete, provides assurance that the intent of the designs has been implemented.

Following the completion of appropriate elements of the start-up program, a series of operational demonstrations was performed focusing on the full CH- and RH-TRU waste handling operations to be used for waste emplacement, as well as the demonstration of retrievability of both waste types. These demonstrations included mock CH- and RH-TRU waste retrieval demonstrations and CH- and RH-TRU waste preoperational checkouts. To further ensure that WIPP will operate safely, two oversight programs have been implemented. An Operational Readiness

Review is providing a comprehensive check on safety, administrative, and operational aspects of the WIPP systems. A comprehensive Preoperational Appraisal, independent of WIPP management, is providing a thorough review of the WIPP environmental, safety, and health programs with an in-depth inspection of the site facilities, and a review and analysis of operations and supporting documentation.

1.2 OBJECTIVES OF THE TEST PHASE

The purpose of the Test Phase is to continue activities in support of the intent of Congress to demonstrate safe disposal of defense wastes and thereby establish a permanent disposal facility for TRU waste. To accomplish this, the WIPP Project will conduct its operations in compliance with applicable laws and regulations. The Project will demonstrate that it is in compliance with the appropriate requirements of the EPA Standard, 40 CFR 191, which regulates TRU waste management and disposal, and will acquire data to support the demonstration presented in its No-Migration Variance Petition, which was prepared to satisfy the requirements of the RCRA Land Disposal Restrictions, 40 CFR 268, Section 6. This Plan addresses the long-term performance requirements of the repository as given in 40 CFR 191, Section 13, Containment Requirements, and Section 15, Individual Protection Requirements, for which the WIPP Project will use performance-assessment techniques. 40 CFR 191, Section 14, Assurance Requirements, and Section 16, Ground Water Protection Requirements, do not require the use of performance-assessment techniques and are not discussed here.

Although Subpart B of the Standard was remanded to the EPA by the U.S. Court of Appeals for the First Circuit, this Plan addresses the Standard as first promulgated. The 1987 Second Modification to the Agreement for Consultation and Cooperation between the DOE and the State of New Mexico (1981) commits the WIPP Project to evaluate compliance with the Standard as first promulgated until a revised Standard becomes available. Compliance plans for the WIPP facility will be revised as necessary in response to any changes to the Standard.

The two primary objectives of the Test Phase are to demonstrate

- Reasonable assurance of compliance of the WIPP disposal system (the combination of the repository/shaft system and the controlled area) with the long-term disposal standards of the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15. Compliance of the disposal system will be determined based on a probabilistic performance assessment, incorporating both data and interpretations developed during the Test Phase. The performance assessment will include an evaluation of potential engineered alternatives.

- The ability of the DOE TRU waste management system (the generating/storage sites, the transportation system, and WIPP) to safely and effectively certify, package, transport, and emplace waste underground at WIPP in accordance with all applicable regulatory requirements. Acceptability of the waste management system will be evaluated by operations testing and monitoring, both individually and collectively, of the TRU waste management system.

The focus of this Plan is to describe the method and activities required to demonstrate compliance with the long-term performance standard of 40 CFR 191, Subpart B, Sections 13 and 15. In addition, several of the tests planned for the Test Phase will provide data that will be used to support WIPP's demonstration that there will be no migration of hazardous constituents of the waste, as required under the RCRA Land Disposal Restrictions, 40 CFR 268, Section 6. The Operations Demonstration Program, which is currently being reevaluated by the DOE, will be presented in a separate program plan.

1.2.1 Performance Assessment

The Performance Assessment Program will evaluate whether the WIPP disposal system can reasonably be expected to isolate TRU waste from the accessible environment after decommissioning in accordance with the requirements set forth in 40 CFR 191, Subpart B, Sections 13 and 15.

1.2.1.1 Requirements of the EPA Standard

The performance objective of the WIPP disposal system is to adequately isolate the waste from the accessible environment; the performance requirements for radionuclides are compliance with the 10,000-year release limits and the 1,000-year dose limits in Subpart B, Sections 13 and 15. In evaluating compliance with Subpart B, the WIPP Project will follow the guidance provided in Appendix B to the EPA Standard. The Standard requires different predictions of disposal system performance for 1,000-year and 10,000-year periods. The Standard specifies that a performance assessment be used to predict the cumulative releases of radionuclides to the accessible environment for the 10,000-year period; cumulative releases must be within the limits established in Appendix A of the Standard. Parts of the WIPP 10,000-year performance assessment methodology can be used to assess compliance with the 1,000-year performance requirements. The 1,000-year assessment will predict annual doses to members of the public in the accessible environment resulting from undisturbed disposal system performance. It will not address the concentration limits established by Subpart B, Section 16, for special sources of ground water, because no such sources exist at WIPP.

The EPA Standard, 40 CFR 191, is procedural; it identifies the approach to be taken and provides explicit guidance for implementation. To show that WIPP can meet cumulative release limits set for the 10,000-year requirements, the performance of the disposal system must be predicted, taking into account all plausible responses to all significant events and processes that might affect the disposal system. To ensure that all plausible responses are identified, scenarios are developed by coupling the individual events and processes that could occur. Scenarios are screened by removing those that fall outside the bounds set by the regulation. Consequence analysis is used to calculate a performance measure for each of the remaining significant scenarios. The performance measures for all remaining scenarios are normalized, summed, and reported as a complementary cumulative distribution function of release probabilities. Uncertainties in the data must be included in calculations of the performance measure for each scenario. To provide a reasonable expectation that the WIPP repository can meet annual dose limits set for 1,000-year performance, the Standard requires that releases from the undisturbed scenario be analyzed. If any release to the accessible environment is predicted, transport along biological pathways is modeled and dose estimates are made. Uncertainties in the data are included in the dose calculations.

The performance assessment will provide quantitative measures of the long-term performance of the WIPP disposal system. EPA recognized that sole reliance on numerical predictions of releases and doses to determine compliance may not be appropriate and acknowledged that such predictions may need to be supplemented with qualitative judgments. The final decision will be based on a reasonable expectation of compliance with Subpart B, Sections 13 and 15, and will include quantitative measures of performance and qualitative judgments.

1.2.1.2 Approach

A framework was established to guide the acquisition of information for Performance Assessment during the Test Phase. The framework consists of five major program elements which identify the major program components required to evaluate compliance (Table 1-1). Elements contain both procedural and technical requirements. Disposal system characterization activities have been developed to provide the data to satisfy these requirements.

Because of the broad scope of each of the elements, they are, in turn, divided into subelements. The subelement consists of more discrete components of the program, which are used to develop specific information needs, as discussed in Chapter 2. For example, Element 1.2, Repository/Shaft System: Behavior Characterization and Performance Modeling, has as one of its subelements, Subelement 1.2.1, Waste Disposal Room Behavior and Modeling. To adequately understand the room behavior and to model its behavior, specific information must be available. One of the information needs for this subelement is Information Need 1.2.1.6, Gas Generation and Behavior. Data for this information need will come from several different activities (e.g., S.1.3.2, Alcove Gas Generation Tests, and S.1.3.3, Bin-Scale Gas Generation Tests), each of which is described in Chapter 2.

1.2.1.3 Performance Assessment Methodology

In performance assessment methodology developed for WIPP (Bertram-Howery and Hunter, 1989a) consists of seven major components: (1) data collection, model development, and engineered alternatives, (2) scenario development and screening, (3) preliminary consequence analysis, (4) sensitivity and uncertainty analysis, (5) final consequence analysis and comparison with the EPA Standard, 40 CFR 191, (6) analysis of undisturbed performance, and (7) documentation. Disposal system characterization (or supporting) activities provide the data, models, and engineered alternatives for the first component, and comprise the bulk of the Performance Assessment Program. The other six components are developed in Performance Assessment activities. Section 2.4.1 provides a detailed explanation of each component.

There are four major areas of scientific investigation integral to the assessment of disposal system performance. These areas examine the behavior of the disposal room and drift system, the sealing system, structural and fluid-flow behavior of the Salado Formation, and non-Salado hydrology and radionuclide migration. Investigation of these areas involves both laboratory and large-scale underground tests.

Model segments are being developed to simulate the response of the disposal system to each process or event within each scenario. Model segments that predict the behavior of the waste disposal rooms, panel seals, access drifts,

Table 1-1. Work Elements and Subelements for Performance Assessment

<u>Element 1.1 Scenario Screening</u>

Subelement 1.1.1	Climatic Change
Subelement 1.1.2	Nuclear Criticality
Subelement 1.1.3	Human Intrusion
Subelement 1.1.4	Seal Performance
Subelement 1.1.5	Probability Assignment

<u>Element 1.2 Repository/Shaft System: Behavior Characterization and Performance Modeling</u>

Subelement 1.2.1	Waste Disposal Room Behavior and Modeling
Subelement 1.2.2	Panel Seal Behavior and Modeling
Subelement 1.2.3	Access Drift Behavior and Modeling
Subelement 1.2.4	Shaft Seal Behavior and Modeling
Subelement 1.2.5	Transport Modeling

<u>Element 1.3 Controlled Area: Behavior Characterization and Performance Modeling</u>

Subelement 1.3.1	Los Medanos Regional Flow Modeling
Subelement 1.3.2	Controlled Area Flow Modeling
Subelement 1.3.3	Hydrologic Transport Modeling
Subelement 1.3.4	Borehole Plug Behavior and Modeling

<u>Element 1.4 Computational System</u>

Subelement 1.4.1	Development of the Compliance Assessment System
Subelement 1.4.2	Compliance Assessment Data Bases

<u>Element 1.5 Consequence Analysis</u>

Subelement 1.5.1	Containment Requirements
Subelement 1.5.2	Individual Protection Requirements

shaft seals, and the migration of radionuclides through the controlled area will be integrated into an overall performance model. This performance model will then be used to predict the consequences of credible scenarios to evaluate compliance with the Standard.

The development of model segments begins with laboratory and field research to identify and begin to assess the individual processes, such as creep closure, brine inflow, gas generation, and migration of radionuclides through panel seals, shaft seals, and overlying water-bearing rock units. While the models are being developed, field and laboratory studies continue acquiring the data necessary for use in the model segments. Among the data collection activities are the tests that have been designed to provide realistic data on TRU waste gas generation and to evaluate the effectiveness of gas getters in the backfill. These tests include laboratory tests with simulated waste; bin-scale tests, which will use approximately six drums of waste per bin to produce conditions representative of long-term effects; and underground (in situ) alcove tests designed to develop gas generation and consumption data that are representative of the heterogeneous mixture of CH-TRU waste. Additional information on these underground tests can be obtained in Chapter 2, Activities S.1.3.2 (p. 2-112) and S.1.3.3 (p. 2-114), and Appendix A.

In addition, the experimental program will collect data to support WIPP's demonstration that hazardous constituents of the waste will not migrate in accordance with a variance petition submitted to the EPA. Key aspects of the experimental program related to RCRA compliance are

- To identify any hazardous components (such as volatile organic compounds and heavy metals) that may be released from the waste in significant quantities,

- To gain greater understanding of potential chemical interactions that may occur between various waste types and between waste and repository host rock, brine, and alternative backfill and gas getter materials,

- To evaluate through a combination of modeling and experimental studies, the expected structural and fluid-flow response of WIPP to internal gas pressurization,

- To evaluate the potential for degradation of the seals and plugs (final design, not temporary inflatable seals) due to exposure to the volatile organic compounds in the waste, and

- To observe and report waste and repository behavior to meet monitoring requirements related to the granting by the EPA of a No-Migration Variance for the WIPP.

In conjunction with the performance assessment activities, the Project will examine engineered alternatives to the current waste disposal system design. It will prepare the Project to implement any necessary changes to the design in a timely manner as a contingency if performance assessment results have a high degree of uncertainty or are unsatisfactory, or if changes are required to enhance the demonstration of no migration as required under RCRA. Examples of types of alternatives under consideration include waste processing and changes in the storage room or panel configuration. Engineered alternatives will be screened for relative effectiveness using a design analysis model and will be screened for feasibility with respect to cost, state of technology, regulatory concerns, and worker exposure; they will then be tested in laboratory or larger scale experiments where possible. Phase 3 bin-scale tests will incorporate appropriate alternatives, and it is possible that some alternatives will be identified early enough to include them in Phases 1 and 2. Potentially effective and feasible alternatives will be evaluated using the formal performance assessment process to quantify the improvement in disposal system performance.

1.2.2 Operations Demonstration

The Operations Demonstration Program plan will be described in a separate document after DOE has evaluated the scope and timing for an Operations

Demonstration based on the recommendations of external technical peer review groups. The purpose of the Operations Demonstration will be to evaluate the ability of the TRU waste management system to provide safe and effective handling, waste certification, transportation, and disposal of the TRU waste at emplacement rates up to those required for full-scale operation of the WIPP facility. This demonstration will include all elements of the DOE TRU waste management system (the generating/storage sites, the transportation system, and WIPP) and require both CH- and RH-TRU wastes. The Operations Demonstration will follow a phased approach that will build upon previous confirmation of facility and operational readiness, cold operations, experience with handling of bin-scale and alcove test waste, and proceed to the next step, full-scale operations with radioactive waste. It will reflect an integrated, stepwise progression of facility readiness, training, nonradioactive operational demonstrations, and demonstrations with radioactive wastes progressing from initial receipt rates to higher quantities representative of required WIPP throughput rates.

Prior to receipt of actual radioactive waste at WIPP, all operational procedures from waste receipt to retrieval and shipment will be checked out with non-radioactive ("cold") non-hazardous materials. Handling and emplacement of TRU waste used for the bin-scale and alcove scale tests will provide some limited experience for the waste management system. Specifically, experience will be gained in preparation and loading of waste at the waste generating/storage facility; transportation and tracking of waste shipments; receipt, unloading, and emplacement of waste; and storage of waste.

1.3 TRU WASTE REQUIREMENTS FOR THE TEST PHASE

An important component of the Test Phase is the need to conduct experiments with actual TRU waste underground in the WIPP repository. The waste will be used to conduct underground (in situ) gas generation tests, which will be used to reduce the level of uncertainty in the performance assessment and will provide data to support WIPP's demonstration that hazardous constituents of the waste will not migrate.

The Performance Assessment Program requires simulation of the WIPP disposal system and an evaluation of the consequences of credible release scenarios. An adequate understanding of the disposal room behavior is an important element of these consequence predictions. As part of the characterization of the room, gas generation and consumption by microbial and radiolytic decomposition of the TRU waste and corrosion of the waste containers, as well as the influx of naturally occurring gas from the host rock, must be evaluated. This evaluation will include two basic types of tests conducted in the WIPP underground: bin-scale and alcove tests (Table 1-2). Data from monitoring an estimated 124 specially designed bins will be used to verify laboratory data concerning gas generation during the postoperational phase of the facility. Additional test bins may be required to accommodate potential test contingencies, specifically including any new engineered modifications to waste and backfill. In the alcove tests, which represent both initial operational conditions and postoperational conditions, an estimated total of 3,850 drums of CH-TRU waste will be emplaced in specially mined alcoves in the WIPP facility. Chapter 2, Performance Assessment, and Appendix A, Tests with CH-TRU and Simulated Wastes,

Table 1-2. Waste Type and Quantity for Gas-Generation Tests[1]

ALCOVES			
Phase	Alcove	Type	Drums
Phase 1	TA1		None: baseline
Phase 1	TA2	As-Received	1,050
Phase 2	TA3	Prepared	1,050
Phase 2	TA4	Compacted	350
Phase 2	TA5	Prepared	1,050
Phase 2	TA6	Compacted	350
Total			3,850

BINS		
Phase	Bins	Drum-Equivalents
Phase 1	48	252
Phase 1	4	None: baseline
Phase 2	68	356
Phase 2	4	None: baseline
Phase 3	TBD	TBD
Total	124	608

[1]This table does not include additional quantities for the Test Phase that may be required to support additional bin-scale tests for evaluation of engineered alternatives, a request by the EPA to instrument and seal two full-scale rooms of waste, and the Operations Demonstration. These programs are currently being evaluated by the DOE.

provide further descriptions of the TRU waste requirements for the EPA compliance effort.

Although the initial part of the Test Phase is well defined, experimental programs will evolve with increasing understanding of the systems under test. The nature, scope, waste quantities, and timing of experiments and full-scale rooms recommended by various groups remain flexible. The sum total of waste for these tests would initially require approximately 2 percent by volume of the design capacity.

The initial plans for the Test Phase described in this document call for the emplacement of approximately 0.5 percent by volume of the design capacity for Phases 1 and 2 of the alcove tests and Phases 1 and 2 of the bin-scale tests. These bin-scale and alcove tests will support assessment of compliance with the

EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15, and the RCRA Land Disposal Restrictions, 40 CFR 268, Section 6. Additional tests will be defined based on the data acquired during the first two phases of the bin-scale and alcove tests and to incorporate potential engineered alternatives.

In addition, the EPA has requested that the Project monitor the performance of the facility by emplacing waste in two full-scale, instrumented, backfilled, sealed rooms after an appropriate demonstration of retrieval using simulated waste. Waste requirements for these two full-scale room tests would be approximately 1.5 percent by volume of design capacity. The DOE will conduct a feasibility evaluation to determine the best technical approach, scope, and timing of such monitoring. The DOE will consult the NAS/NAE WIPP Panel, the EPA, the State of New Mexico, and the EEG prior to initiation of such tests.

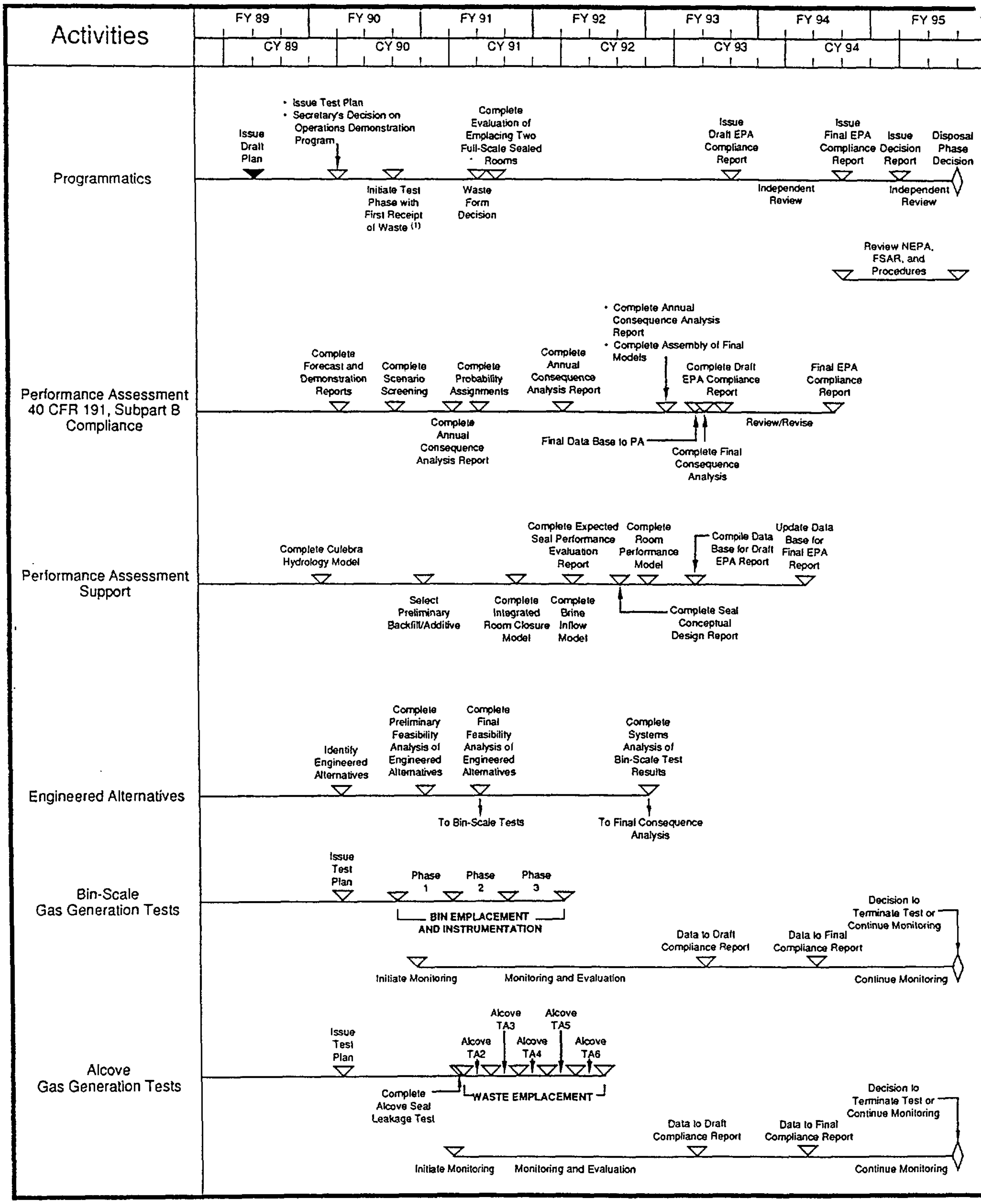
Also, waste requirements for an Operations Demonstration have not yet been determined. The DOE will evaluate the operational experience to be gained through the conduct of all of the test activities and will factor this into future decisions on the scope and timing of an Operations Demonstration. Waste emplaced in the WIPP facility during the Test Phase will be retrievable until a decision is made whether WIPP should become a disposal facility. During the Test Phase, per agreement with the State of New Mexico, WIPP will meet the applicable requirements of the EPA Standard, 40 CFR 191, Subpart A.

1.4 SCHEDULE

The Test Phase is scheduled to begin in July 1990 (Decision Plan, Rev. 0) with the first receipt of waste for bin-scale and alcove gas generation tests and will continue for about five years (Figure 1-5). At the end of the Test Phase, a decision is scheduled to be made whether WIPP will become a permanent repository for TRU waste. To support this decision, a Test Phase Decision Report will be issued in January 1995, containing summaries and conclusions from the major programs (e.g., 40 CFR 191 compliance, Operations Demonstration, RCRA) conducted during the Test Phase. This report will be issued to appropriate external organizations for review prior to the decision date.

Many of the performance assessment and disposal system characterization activities shown in the summary schedule. Figure 1-5, have been in progress for several years and will continue into the Test Phase. The nature and scope of these on-going experimental studies have been guided by past sensitivity analysis and disposal system performance calculations. The approach that is being taken in demonstrating compliance with the EPA Standard, 40 CFR 191, and in guiding the experimental program will place more emphasis on sensitivity analysis and disposal system performance calculations. This approach is illustrated by the iterative nature of the process. Until issuance of the Draft EPA (40 CFR 191) Compliance Report, which is scheduled for June 1993, the Project will be performing an iterative set of performance assessment calculations every six months, using the most recent models and data sets available from the experimental activities. The results of these interim consequence analyses will be provided in briefings to the NAS/NAE WIPP Panel, the EPA, the State of New Mexico, and the EEG every six months, and documented in a report to be issued for external distribution on an annual basis.

The date for issuance of the Draft Compliance Report is scheduled for June 1993, with the Final Report to be issued June 1994. These dates are predicated



(1) Based on the Secretary of Energy's decision on WIPP readiness as identified in the Decision Plan, Rev. O, dated October 11, 1989.

Figure 1-5. Summary Schedule for the Test Phase on obtaining the required data from the experimental program such that the parameter and system uncertainties are sufficiently reduced and there is reasonable assurance that WIPP will comply with the 40 CFR 191 Standard, as well as other applicable environmental regulatory requirements. If reasonable assurance of compliance cannot be demonstrated due to an inadequate data base or if new technical concerns arise and require investigation, the target date will be revised accordingly. Alternatively, if WIPP cannot be shown to comply with the 40 CFR 191 Standard, or other applicable environmental requirements, the site will not be used for radioactive waste disposal.

The schedule for the experimental program indicates that all planned experiments will provide the data needed to demonstrate compliance by June 1994. Two activities of special interest to the performance assessment analyses are the bin-scale and alcove gas generation tests and the engineered alternatives study. Prior to emplacing experimental waste in the alcoves, a seal leakage test must be completed and the leakage rate found acceptable. The gas generation tests assume an incremental approach to testing, from initial emplacement of simple waste/backfill combinations to emplacement of increasingly more complex experiments incorporating compacted waste and potential engineered alternatives. Potential engineered alternatives, such as modifications to the waste form and/or backfill, will be incorporated into the Phase 3 bin-scale tests, and possibly in Phases 1 or 2 if the engineered alternatives study identify any potentially feasible alternatives.

It is expected that useable data will be available from the bin-scale tests approximately six months after emplacement of the bins and approximately 12 months after initiation of each alcove test. Gas generation data will be available for incorporation into the 1993 Draft Compliance Report from all three phases of the bin-scale tests, including testing of engineered alternatives and/or backfill, and from the first four alcoves (TA1 - TA4). Prior to issuance of the 1994 Final Report, the gas generation data will be updated and expanded to include data from Alcoves TA5 and TA6, which will incorporate the combined effects of waste and emplaced backfill, and may incorporate potential engineered alternatives. Following issuance of the Final Report, gas generation data will continue to be gathered from all bin and alcove tests until the end of the Test Phase to confirm the estimates of gas generation used in predicting the repository behavior. Should significant differences between the gas generation estimates used in predicting the repository behavior and the updated test results occur, the repository performance would be reevaluated.

Several other activities, such as the large-scale seal test and the brine room (Room Q) test, will continue to gather data beyond the 1994 Final Compliance Report issuance date. They will provide data to confirm any estimates or assumptions and to increase confidence in the analyses of disposal system behavior.

1.5 ORGANIZATION OF THE PLAN

The remainder of this Plan discusses details of the program:

- Chapter 2 - Performance Assessment: This chapter presents the methodology and specific activities designed to provide a confident assessment of the disposal system performance.

- Appendix A - Tests with CH-TRU and Simulated Wastes: This appendix provides detailed background and rationale for the waste tests, and summarizes the methods to be used and the information to be gained.

- Appendix B - Comments and responses on the previous draft of this plan: This appendix provides comments from the EPA, the NAS/NAE WIPP Panel, and the EEG, and the DOE's responses to those comments.

2.0 PERFORMANCE ASSESSMENT

Investigations at the WIPP site have been underway for almost 15 years; only during the past four years has a regulatory standard governing releases of radioactive waste from WIPP been in place. Early investigations were somewhat generic, and they examined specific processes (e.g., meteorite impact), parameter values (e.g., 1,000,000 years), and repository-design considerations (e.g., high level waste) that have now been resolved. Past investigations, external review by groups like the NAS/NAE WIPP Panel and the State of New Mexico, and the EPA Standard (EPA, 1985) have made it possible to focus more sharply on the factors that are most likely to influence compliance with the regulatory standards and that are of concern to the technical oversight community. For example, shorter time periods, i.e., 10,000 years, are now of interest, and the analysis must be probabilistic. Before 1985, no regulatory standard was in place, so the approach taken to showing the adequacy of the site and design was completely safety-oriented. For example, the Final Environmental Impact Statement (FEIS; DOE, 1980) calculated doses to persons arising from transport of radionuclides to the Pecos River.

The DOE has performed several relatively short-term studies to ensure that the WIPP Performance Assessment and experimental program, which is a multi-year effort, is heading in the right direction. Both the FEIS (DOE, 1980) and the draft Supplement to the Environmental Impact Statement (SEIS; DOE, 1989b) were prepared to evaluate the environmental impacts and safety of the repository using conservative assumptions about important parameters. The draft SEIS examined two scenarios that are known to be of interest during the final performance assessment: undisturbed performance and human intrusion. The draft SEIS demonstrated that the doses that arise, even after human intrusion through the repository and into a brine pocket, are small or negligible for expected rock and waste properties, in comparison with radiation standards protecting members of the public. Even for rock and waste properties substantially worse than expected, doses after many years of exposure are roughly equal to background radiation doses (DOE, 1989b, e.g., Tables 5.54 and 5.61). By the end of 1989, two "demonstration documents" (Bertram-Howery et al., 1989, Forecast of the Final Report for the Comparison with EPA 40 CFR 191, Subpart B, for the WIPP; Marietta et al., 1989, Performance Assessment Methodology Demonstration: Methodology Development for Purposes of Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the WIPP) will be published; they will also examine a limited number of scenarios that are known or thought to be particularly important. The Methodology Demonstration will contain a preliminary probabilistic analysis of the cases examined in the draft SEIS. The demonstration will show how the performance assessment methodology is applied to the undisturbed scenario and to several human intrusion scenarios that are considered to present the most difficulty in showing compliance with the standard. The calculations and analyses necessary for the demonstration will show how the "total system" models are used iteratively for examining priorities in experimental programs. The Forecast will have the same scope and table of contents as the Final EPA (40 CFR 191) Compliance Report and will allow all interested parties to iteratively review the projected format of the report prior to reviewing the results of the performance assessment. Similar demonstration documents will be published annually to show the progress of the performance assessment.

This chapter documents the information needs and activities that will be performed to determine compliance with the EPA Standard, 40 CFR 191, Subpart B, Sections 13 and 15. Section 13, the Containment Requirements, and Section 15, the Individual Protection Requirements, require predictions of releases of radionuclides for 10,000 years and doses for 1,000 years, respectively. The term "performance assessment" is used herein to refer to the prediction of long-term performance for both requirements. In this Plan, the elements and activities related to evaluation of compliance with the Standard focus on long-term performance for these two requirements. A more detailed presentation of the background and descriptions of the performance assessment and supporting activities that will be performed during the Test Phase can be found in a report by Bertram-Howery and Hunter (1989b) entitled Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant. Additional information on the performance assessment methodology is available in Plans for Evaluation of the Waste Isolation Pilot Plant's Compliance with EPA Standards for Radioactive Waste Management and Disposal (Bertram-Howery and Hunter, 1989a).

This chapter is organized as follows. Section 2.1 briefly describes the EPA Standard, 40 CFR 191, Subpart B. A brief summary of the performance evaluation presented in the WIPP FEIS (DOE, 1980) and the draft SEIS (DOE, 1989b) is presented in Section 2.2. Section 2.3 discusses the factors that affect the long-term performance of the disposal rooms. An overview of the technical approach for the determination of compliance with Subpart B of the EPA Standard is provided in Section 2.4, and a description of the WIPP Performance Assessment Program is contained in Section 2.5. Descriptions of the work elements and information needs are presented in Section 2.6. Section 2.7 summarizes the activities to be performed to complete the performance assessment, and Section 2.8 describes the scheduling of activities.

2.1 BRIEF DESCRIPTION OF 40 CFR 191, SUBPART B

The EPA Standard, 40 CFR 191, is divided into two subparts. The application of both Subpart A and Subpart B of the Standard to WIPP is described in the report, Waste Isolation Pilot Plant Compliance Strategy for 40 CFR Part 191 (DOE, 1989d), which discusses the application of various terms and definitions contained in the Standard to WIPP. Although Subpart B of the Standard was remanded to the EPA by the U.S. Court of Appeals for the First Circuit, this Plan addresses the Standard as first promulgated. The 1987 Second Modification to the Agreement for Consultation and Cooperation between the DOE and the State of New Mexico (1981) commits the WIPP Project to evaluate compliance with the Standard as first promulgated until a revised Standard becomes available.

Subpart A applies to a disposal facility prior to decommissioning and limits annual radiation doses to members of the public from waste management and storage operations. Subpart B applies for the most part after decommissioning and limits cumulative releases of radioactive materials to the accessible environment for 10,000 years. Subpart B also limits both annual radiation doses to members of the public in the accessible environment and radioactive contamination of certain sources of ground water for 1,000 years after disposal. Table A in Appendix A to the Standard specifies how to determine the 10,000-year release limits, and Appendix B provides nonmandatory guidance for implementation of Subpart B. The four sections of Subpart B, the associated definitions, and two appendices establish a framework of procedures to be applied in complying with the Standard. Terms from the Standard important to the discussions in this Plan are briefly discussed below.

As defined in the Standard, "disposal" will occur after the waste is permanently emplaced underground and the repository and shafts are sealed. "Accessible environment" is defined in the Standard as: (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all of the lithosphere beyond the controlled area.

The concept of "sites" is integral to Subparts A and B limits on releases of waste from the repository or disposal facility, both during operation and after closure. "Site" is used differently in the two subparts. Passive institutional control of the controlled area (Figure 2-1), which is important to determining compliance with Subpart B of the Standard, depends on the definition of "site." "Site" has also been used generically for many years by the waste management community (e.g., in the phrases "site characterization" or "site-specific"); few generic uses of the word correspond to either of the EPA's usages. However, "site" is used both in the sense of the Standard and generically in this Plan.

The term "disposal site" as used in Subpart B and Appendix B to the Standard differs from "site" as defined for Subpart A. For the purposes of the WIPP strategy for compliance with Subpart B, the disposal site, which must be marked for protection of future generations, is the same as the controlled area. The controlled area for Subpart B includes the surface and subsurface of the secured area and additional surrounding areas, the extent of which will be determined during the performance assessment (DOE, 1989d). The Standard limits the controlled area to the region within 3 mi (5 km) of the waste panel boundaries; it will not be less than the area withdrawn.

Sections 13 and 15 of 40 CFR 191, Subpart B, the Containment Requirements and Individual Protection Requirements, necessitate predictions of releases of radionuclides for 10,000 years and doses for 1,000 years, respectively.

Section 14 of 40 CFR 191, Subpart B, contains the Assurance Requirements, which complement the Containment Requirements. No testing is required to satisfy Section 14; therefore, it is not addressed in this Plan. The Assurance Requirements implementation plan contains additional information (Westinghouse, 1987).

Section 16 of 40 CFR 191, Subpart B, protects "special sources of ground water" from contamination at concentrations greater than certain limits. This is the only requirement in the Standard that limits radionuclide concentrations. No ground water within 3 mi (5 km) of the maximum allowable extent of the controlled area satisfies the definition of a "special source of ground water." Therefore, the WIPP Project will comply with this requirement by documenting that no "special source of ground water" exists. No additional data acquisition or analysis is necessary for compliance with this requirement.

Appendix A to the Standard establishes the release limits for all the regulated radionuclides. Table 1 in that appendix gives the limit for cumulative

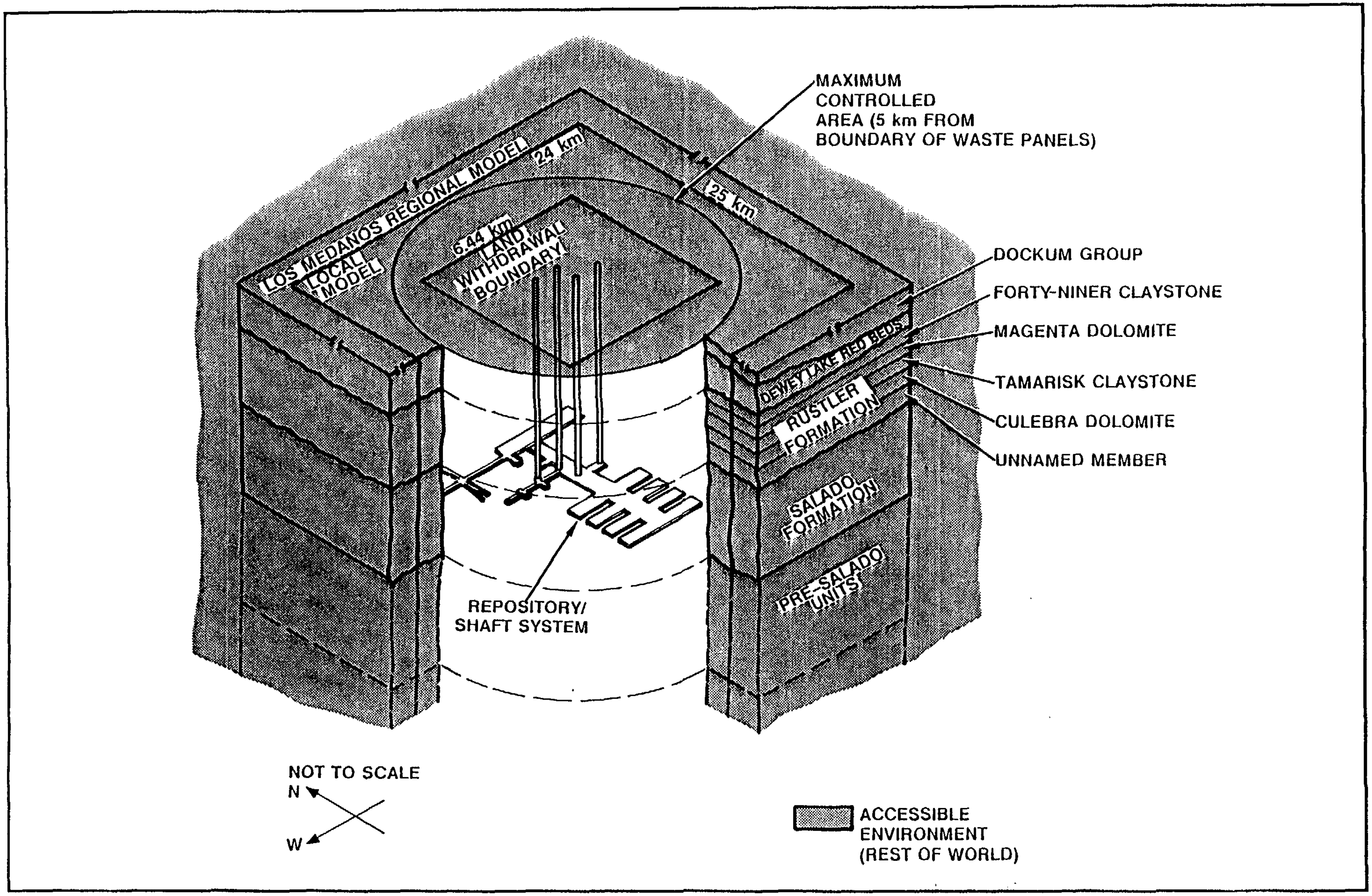


Figure 2-1. Cutaway View of the Controlled Area and the Repository/Shaft System

releases, per unit of waste, to the accessible environment for 10,000 years after disposal for each radionuclide. Note 1(e) to Table 1 defines the unit of waste as an amount of TRU wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years. Note 2(b) describes how to develop release limits for a TRU waste disposal system: the release limits are the quantities in Table 1 multiplied by the number of units of waste in the repository. Note 6 describes the manner in which the release limits are to be used to determine compliance with Section 13: for each radionuclide released, the ratio of the cumulative release to the total release limit for that radionuclide must be determined; the ratios for all radionuclides released are then summed for comparison to the requirements of Section 13. Thus the quantity of a radionuclide that may be safely released depends on the quantities of all other nuclides projected to be released, but cannot exceed its own release limit. The summed normalized release cannot exceed 1 for probabilities greater than 0.1 and cannot exceed 10 for probabilities greater than 0.001. Releases that occur with probabilities less than 0.0001 are not regulated.

Appendix B to the Standard is EPA's guidance to the implementing agency (in this case, the DOE). In the preamble to the Standard (EPA, 1985, p. 38069), the EPA states that it intends the guidance to be followed: "...Appendix B...describes certain analytical approaches and assumptions through which the [EPA] intends the various long-term numerical standards of Subpart B to be applied. This guidance is particularly important because there are no precedents for the implementation of such long-term environmental standards, which will require consideration of extensive analytical projections of disposal system performance." The EPA based Appendix B on some of the analytical assumptions it used to develop the technical basis for the numerical disposal standards. Thus, the EPA "believes it is important that the assumptions used by the [DOE] are compatible with those used by the EPA in developing this rule. Otherwise, implementation of the disposal standards may have effects quite different than those anticipated by EPA" (EPA, 1985, p. 38074).

The primary objective of Subpart B is to ensure that the disposal system will isolate the waste from the accessible environment by limiting long-term releases and the associated risks to populations. This objective is reflected in the Containment Requirements. Evaluation of compliance is based on a performance assessment, which has specific meaning within the Standard:

> "Performance Assessment" means an analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable (40 CFR 191, Section 12[q]).

Subpart B limits risks to individuals in ways compatible with the primary objective (EPA, 1985, p. 38070). The methodology developed for performance assessment can be used to predict releases so that doses can be predicted as specified by the Individual Protection Requirements. This dose assessment must provide a reasonable expectation that the annual dose equivalent from the disposal system to any member of the public in the accessible environment will not exceed 25 millirems to the whole body or 75 millirems to any critical organ. The Standard requires that modeled individuals be assumed to consume 2 liters (2.1 quarts) of drinking water per day from a "significant source of ground water" outside the controlled area. These requirements apply to undisturbed performance of the disposal system, considering all potential release and dose pathways, for 1,000 years after disposal:

> "Undisturbed performance" means predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events (40 CFR Part 191.12[p]).

Unlikely natural events are those that have not occurred rapidly enough in the past to affect the Salado Formation at the repository horizon within the controlled area so as to have caused the release of radionuclides, had they been present. Only the presence of ground water has affected the Salado Formation in the vicinity of WIPP at the repository horizon for the past several million years. Therefore, the WIPP Project will simulate only ground-water flow and the effects of the repository as the undisturbed performance (DOE, 1988).

The EPA defines a "significant source of ground water" as

> (1) An aquifer that: (i) Is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per square foot; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of a least a year; or (2) an aquifer that provides the primary source of water for a community water system as of November 18, 1985 (40 CFR Part 191, Section 12[n]).

No water-bearing unit in the vicinity of WIPP meets the EPA's first definition of a "significant source of ground water" throughout its extent because the level of dissolved solids is high and the transmissivity is low in most places (Mercer, 1983; LaVenue et al., 1988; Siegel et al., 1988); however, the WIPP Project will assume that any portion of a water-bearing unit that meets the first definition is a "significant source of ground water." Communication between nonqualifying and qualifying portions will be evaluated. No water-bearing unit near the WIPP facility meets the EPA's second definition of "significant source of ground water."

The Project does not expect releases to occur outside the controlled area within 1,000 years; therefore, dose calculations for the undisturbed performance may be unnecessary outside the controlled area. Recent calculations for site characterization suggest that, under modern head gradients, ground-water travel time from the center of the site (essentially the tops of the shafts) to the land withdrawal boundary is significantly longer than 1,000 years (Reeves et al., 1987; LaVenue et al., 1988). If the performance assessment predictions of travel times from the repository, up the shafts into the Culebra Dolomite Member, and to the boundary of the controlled area corroborate this, no radionuclides could be transported to a significant source of ground water outside the controlled area within the time of regulatory interest. The nearest aquifer that is certainly a significant source of ground water is the Pecos Valley alluvial fill at Malaga Bend, 16 mi (26 km) away. The Project does not plan to predict transport of radionuclides so far outside the controlled area. The current understanding of ground-water flow strongly indicates that such a prediction will not be required.

The EPA acknowledged that implementation of the Containment Requirements might require modification of those standards in the future. This implementation "will require collection of a great deal of data during site characterization, resolution of the inevitable uncertainties in such information, and adaptation of this information into probabilistic risk assessments. Although EPA is currently confident that this will be successfully accomplished, such projections over thousands of years to determine compliance with an environmental regulation are unprecedented. If - after substantial experience with these analyses is acquired - disposal systems that clearly provide good isolation cannot reasonably be shown to comply with the containment requirements, the EPA would consider whether modifications to Subpart B were appropriate" (EPA, 1985, p. 38074).

EPA recognized that Subpart B must be implemented in the design phase because active surveillance cannot be relied upon over the very long time frames of interest. EPA also recognized that the Standard "must accommodate large uncertainties, including uncertainties in our current knowledge about disposal system behavior and the inherent uncertainties regarding the distant future" (EPA, 1985, p. 38070).

Both the Containment Requirements and the Individual Protection Requirements require a "reasonable expectation" that their various quantitative tests can be met, to "acknowledge the unique considerations likely to be encountered upon implementation of these disposal standards" (EPA, 1985, p. 38071). The Standard "clearly indicates that comprehensive performance assessments, including estimates of the probabilities of various potential releases whenever meaningful estimates are practicable, are needed to determine compliance with the containment requirements" (EPA, 1985, p. 38076). These requirements "emphasize that unequivocal proof of compliance is neither expected nor required because of the substantial uncertainties inherent in such long-term projections. Instead, the appropriate test is a reasonable expectation of compliance based upon practically obtainable information and analysis" (EPA, 1985, p. 38076). The EPA believes that the Standard requires "very stringent isolation while allowing the [DOE] adequate flexibility to handle specific uncertainties that may be encountered" (EPA, 1985, p. 38076).

The EPA's assumptions regarding performance assessments and uncertainties are incorporated in Appendix B to the Standard, which the EPA intends the implementing agencies to follow. EPA intended these assumptions to "discourage overly restrictive or inappropriate implementation" of the requirements (EPA, 1985, p. 38077). The guidance in Appendix B to the Standard indicates that "compliance should be based upon the projections that the [DOE] believes are more realistic....Furthermore,...the quantitative calculations needed may have to be supplemented by reasonable qualitative judgments in order to appropriately determine compliance with the disposal standards" (EPA, 1985, p. 38076). In particular, Appendix B states

> The [EPA] believes that the [DOE] must determine compliance with §§191.13, 191.15, and 191.16 of Subpart B by evaluating long-term predictions of disposal system performance. Determining compliance with §191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the [DOE] to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the [DOE] may choose to supplement such predictions with qualitative judgments as well.

In Section 13(b), the Containment Requirements state that

> Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not available in the ordinary sense of the word when compared to situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the (DOE), that compliance with 191.13(a) will be achieved.

The EPA recognized that there are too many uncertainties in projecting the behavior of natural and engineered components for 10,000 years and too many opportunities for errors in calculations or judgments for the numerical requirements to be sufficient for determining disposal system acceptability. Qualitative requirements were included in the Standard to ensure that "cautious steps are taken to reduce the problems caused by these uncertainties" (EPA, 1985, p. 38079). These qualitative Assurance Requirements are an essential complement to the quantitative Containment Requirements. Each qualitative requirement was chosen to compensate for some aspect of the inherent uncertainty in projecting the future performance of a disposal system. The Assurance Requirements state that compliance with their provisions will "provide the confidence needed for long-term compliance with the requirements of 191.13." A WIPP Project document (Westinghouse, 1987) has been prepared to guide future program implementation of the Assurance Requirements.

The determination of compliance with Subpart B depends on the calculated complementary cumulative distribution function and the calculated doses; however, it also depends on the strength of the assurance strategies that will be implemented and on the qualitative judgment of the DOE and its analysts. The preceding discussion clearly demonstrates the EPA's recognition of the difficulties involved in predicting the future and in quantifying the outcomes of future events. It also shows that the EPA expects the DOE to understand the uncertainties in the disposal system's behavior only to the extent practical.

One type of uncertainty that cannot be completely resolved is the validity of available models for predicting disposal system behavior 10,000 years into the future. Although models will be validated to the extent possible, expert judgment must be relied upon where validation is not possible. In the case of competing conceptual models, if a single conceptual model cannot be demonstrated to be the most consistent with available data, the most conservative conceptual model that is consistent with the data will be used.

2.2 PERFORMANCE EVALUATION IN THE ENVIRONMENTAL IMPACT STATEMENTS

The adequacy of the WIPP disposal system to isolate TRU waste was considered in the WIPP Final Environmental Impact Statement (DOE, 1980) and in the draft SEIS (DOE, 1989b). Both evaluations of performance were deterministic, in contrast to the requirement of the EPA Standard, 40 CFR 191, which specifies that a probabilistic performance assessment be done. Although the methodology used for these evaluations would not satisfy the procedural requirements of the EPA Standard, the results do provide an indication that WIPP geologic environment will safely isolate wastes.

Calculations in the FEIS included two "worst-case" analyses that represented physically plausible extremes for fluid disruption of the repository and for human intrusion into the repository (DOE, 1980). One scenario assumed that all the water flowing in the Rustler Formation above the repository was diverted through the repository and back to the Rustler Formation. The other scenario assumed that material from a waste container was carried directly to the surface. The probability of occurrence of scenarios was not estimated. Uncertainty analyses were not performed, although the calculations were considered reasonably conservative. Cumulative releases were not calculated; instead, peak releases and their times of occurrence were predicted. The maximum peak release predicted in the Final Environmental Impact Statement to occur at Malaga Bend was 2 x 10^{-4} curies per year 1,200,000 years after decomissioning. The maximum peak release at 3 mi (4.8 km) was 3.3 x 10^{-4} curies per year at 400,000 years. Fifty-year dose commitments (integrated dose from a one-year intake) were estimated for all scenarios and found to be significantly less than natural background at the WIPP site.

The draft SEIS evaluated two basic long-term release scenarios expected to bound potential impacts that could result from the long-term disposal of TRU waste at WIPP. The first scenario examined the long-term performance of an undisturbed repository. The second scenario examined a hypothetical intrusion into the repository by an exploratory borehole passing through the repository into a pressurized brine reservoir below. The first scenario, with two variations, used expected, mid-range values for the various input parameters. In the second scenario, which had four variations, the flow and transport properties were intentionally degraded (i.e., the transport of potential contaminants was greatly increased), in order to evaluate long-term repository behavior under more severe, less probable conditions. Additionally, in three of the variations, potential engineered modifications (e.g., precompaction of waste) were postulated to at least partially mitigate the effects of this behavior. Therefore, these scenarios predict the undisturbed and disturbed behavior of the repository under both expected conditions and under more pessimistic conditions. As in the FEIS, the probability of occurrence of scenarios was not estimated.

Both radiation exposure and lead intake for the most exposed individual were calculated in the draft SEIS. In the two versions of the first scenario that treat the undisturbed repository, no radionuclides would reach the ground water or the surface within 10,000 years; therefore, there is no potential for human exposure within that time.

In all versions of the second scenario in the draft SEIS, radioactive material and lead would be brought to the surface immediately. Resultant exposures to the drill crew and a nearby downwind ranch family were about two orders of magnitude below usual guidelines (e.g., 100 mrem/yr general dose limit established by the International Commission on Radiation Protection). The expected behavior of the disturbed repository is well within these guidelines and natural background radiation exposure levels. If, however, the ground-water flow parameters are considerably poorer than expected, the doses predicted are at or above the radiation guidelines. The highest total dose would occur in the case in which transport parameters were degraded and no engineered modifications were postulated to minimize the impacts; the peak is 129 mrem/50 yr about 1500 years after the intruding borehole is plugged and abandoned. Precompaction of the waste was estimated to reduce the predicted doses by 44 percent. Similarly, degraded conditions combined with possible mitigation measures result in predicted committed doses which are well within applicable guidelines.

In contrast, the Standard promulgated in 1985 required that the WIPP disposal system's impact on the accessible environment (as defined by the EPA) be calculated quite differently. Cumulative radionuclide releases to the accessible environment (at the site boundary and on the surface of the controlled area) over the 10,000 years following repository closure must be predicted. The annual dose to man resulting from any releases to the accessible environment must also be predicted for 1,000 years after closure, considering only the undisturbed performance of the disposal system and including drinking from a significant source of ground water outside the controlled area. Both sets of predictions must consider the uncertainties associated with the disposal system's performance. The release predictions are presented as a single complementary cumulative distribution function, which incorporates the probabilities and the parameter uncertainties of all the scenarios.

2.3 FACTORS AFFECTING THE LONG-TERM PERFORMANCE OF THE DISPOSAL SYSTEM

An accurate assessment of the long-term performance of the disposal system requires an understanding of disposal room behavior during and after the consolidation process; an understanding of the effectiveness of the panel and shaft seals; and an understanding of the effectiveness of the local geology and hydrology in preventing or retarding the transport of radionuclides to the environment.

The objective of this section is to summarize the present understanding of the long-term performance of the disposal system and draw upon the extensive amount of work completed to date for WIPP. The discussion briefly considers (1) creep closure of the WIPP underground workings, including the disturbed rock zone; (2) brine seepage both into and out of the excavations; (3) gas generation, consumption, and transport as a result of radiolytic, biological, or corrosion reactions involving emplaced waste and waste containers; (4) sealing of the shafts and panels; and (5) hydrologic and radionuclide-transport characteristics of the overlying and underlying strata.

2.3.1 Room Closure Rates

The observed closure behavior of openings at the facility horizon is more rapid and more complex than expected prior to underground experience. In fact, both the total macroscopic wall-to-wall and ceiling-to-floor closure to date and present closure rates (after five years) are approximately three times those originally expected. Ignoring possible complications, the more rapid closure results in time estimates of 60 to 200 years for closure to a near final state, depending on the initial waste and backfill density, brine influx rate, and creep closure rate.

Certain structural effects or processes resulting from excavation of the rooms were not fully anticipated prior to underground experience. The observed excavation effects result in the formation of a disturbed rock zone at the facility horizon (Borns and Stormont, 1988). At present, the significantly disturbed zone extends approximately 7 ft (2 m) from the underground workings. However, it has not been possible to include the disturbance due to excavation in numerical modeling to date, nor is there consensus concerning its long-term importance.

The disturbed rock zone has the following characteristics:

1. Volumetric dilation as a result of grain boundary opening, as evidenced by detailed geophysical surveys.

2. Macroscopic fracturing as a result of opening preexisting fractures and generating new structures, extending from at least the base of Marker Bed 139 (about 5 ft (1.5 m) below the floor of the disposal horizon) to anhydrite "b" (about 7 ft (2 m) above the top of the disposal horizon).

3. Increases in apparent permeabilities (as interpreted from gas injection tests) by as much as several orders of magnitude, from a few nanodarcies (or less) in the far field to the darcy range in the very near field.

4. An apparent decrease in rock mass shear modulus (decreased mechanical strength), as a result of grain boundary dilation or macroscopic fracturing.

5. Growth of zones of partial hydrologic saturation and/or two-phase flow, as a result of some combination of volumetric dilation at a rate faster than brine inflow, rock mass dehydration by ventilation, and two-phase (gas driven) flow in response to near-field depressurization of gas charged brines.

Two conceptual levels of complexity in the mechanical closure behavior of the Salado Formation are at least partially consistent with available data. The existing model, amenable to numerical modeling, is based on the interpretation that coherent creep of the Salado Formation will dominate the system, independent of any disturbed rock zone that might develop. With this model, more rapid macroscopic closure is strictly beneficial. The model assumes (1) that any disturbed rock zone is very small in volume and importance relative to the volume of deforming portions of the Salado Formation, and (2) that any disturbed rock zone developed during closure will be eliminated by the back pressures exerted by the waste and backfill emplaced in rooms and drifts. Mechanical back pressures are not expected to be generated until the waste and backfill are compacted to approximately 95 percent of their final state of density. Thus, removal of a disturbed rock zone by back pressure, especially if the disturbed rock zone has expanded to include anhydrite, will not occur until very late in the closure process.

The second level of conceptual complexity, based on underground observation of the disturbed rock zone, also assumes that coherent creep of the Salado Formation outside the disturbed rock zone is the major structural process involved in repository closure. However, observation suggests that the disturbed rock zone may

1. Serve as a "sink" for some or all of the brine that seeps into the rooms and shafts by storing brine in macroscopic fractures and perhaps the volumetrically dilated zone, thus resulting in a more complex, time- and geometry-dependent brine behavior than expected in the absence of a disturbed rock zone.

2. Enlarge the effective room dimensions during closure (not by increasing the total room volume, but by moving the surface at or near atmospheric pressure to the outer boundary of the disturbed rock zone), increasing both the time required for closure to final state and the volumes available for brine inflow beyond those estimated on the basis of wall closure calculations assuming coherent creep.

3. Affect the final degree of closure by extending to intersect the relatively brittle Marker Bed 139 or other more permeable units outside of the Salado Formation and allowing gas and/or brine entry into these units.

4. Complicate the design and/or postemplacement behavior of seals in panel entries, access drifts, and shafts.

Strong structural members, such as pipes and rods, within waste drums emplaced in WIPP may locally prevent complete compaction of waste and backfill under lithostatic load, even in the absence of brine seepage, gas generation, and disturbed rock zone effects. Although such members may result in local zones of increased porosity, it is not clear that these zones will interconnect; i.e., it is not clear that they will themselves result in any effective increase in room-scale permeability.

Two additional facts complicate prediction of the long-term closure behavior of the repository. First, the WIPP waste varies greatly in porosity, mechanical properties, and inorganic and organic chemistry, making it difficult to define the time-dependent geochemical and mechanical state of the waste as a source term for calculations. Second, the present design of the WIPP, even including backfill and getters, calls for the initial postemplacement porosity to be relatively high, approximately 50 percent. As a result, a large reduction of volume within the rooms must occur before final state is reached. Engineered alternatives to mitigate the potential impact of many of the uncertainties discussed in this section would decrease the initial free volume within the rooms, and hence the time required for final closure.

In summary, the uncertainty about the mechanical behavior of the Salado Formation during closure of the WIPP repository does not extend to fundamentally different conceptual models. Far-field coherent creep of the Salado Formation is considered to be the dominant process involved. The present uncertainty concerns only the time-dependent extent and possible role of the disturbed rock zone observed to develop in the underground facility.

2.3.2 Brine Flow or Seepage Within the Salado Formation

There are two major reasons for the difference between brine volumes within WIPP expected prior to underground experience and those observed underground. Prior to underground experience, the possibility of leakage from the Rustler Formation downward into the rooms through the shafts was not considered. Secondly, it was assumed that the Salado Formation contained no free water on grain boundaries.

Leakage from the Rustler Formation (largely the Culebra Dolomite Member) into each of the WIPP shafts does not exceed approximately 6×10^{-2} liters per second, even when the shaft is unlined and no effort is made to control drainage. This amount is minimal compared to that observed in many mines, but it does require control. Accordingly, the WIPP shafts have been lined and grouted through the Rustler Formation, successfully eliminating inflow. This conventional treatment will be adequate to control leakage from the Rustler Formation during the operational lifetime of WIPP, approximately 25 years. After this operational period, shaft seals will be emplaced to eliminate any further leakage.

The occurrence and behavior of brine within the Salado Formation is of greatest interest, however. The presence of brine in the Salado Formation adjacent to the underground workings is indicated primarily by the small "weeps" that commonly develop on the walls shortly after excavation. Small amounts of brine also drain from some of the instrumentation and observation holes in the walls or roofs of the underground or collect in holes emplaced in the floor. The weeps, which are indicated by small salt crusts formed by evaporation of the moisture, are stratigraphically controlled, being more abundant in argillaceous than in clean halite. Rarely does the brine flow rate to the mine face or wall exceed the evaporation rate due to mine ventilation. In fact, growth of the weeps generally ceases less than a year after construction of a given face (Deal and Case, 1987).

In the simplest interpretation, consistent with assumptions prior to underground experience, the transient brine weeps could be interpreted as the direct result of stress-driven flow, with no contribution of flow from the far field, i.e., from beyond the zone that is hydrologically or structurally affected by the presence of the underground workings. Alternatively, it may be assumed that the disturbed rock zone is dilational, that the zone serves as a "sink" for brine flow, and that the outer boundary of the disturbed rock zone represents the "effective room surface" for purposes of fluid flow, i.e., the surface at which fluid pressures are reduced to near atmospheric. In this interpretation, the fact that weep growth on wall surfaces ceases may indicate only that the effective room surface has moved into the rock mass in response to the formation of a disturbed rock zone and may not indicate that the flow rate into the disturbed zone is transient on the same one-year time scale as weep growth.

The time scale of the transient brine seepage behavior should decrease with decreasing geometric scale of measurement. Consistent with this interpretation, a measured near steady-state brine inflow of 5×10^{-8} to 1×10^{-7} liters per second into sealed and unheated test holes (Nowak and McTigue, 1987) has been used as one basis to calculate a permeability supporting long-term Darcy flow in the far field. To date, the best direct measurements of far-field hydraulic conductivity within the Salado Formation are in the range of 10^{-14} to 10^{-16} meters/second (Peterson et al., 1987; Saulnier and Avis, 1988; Tyler et al., 1988). The conductivities calculated from brine inflow to test boreholes are also within this range (Nowak et al., 1988). However, stratigraphic effects have not yet been measured reliably, nor have the relative effects of borehole closure and fluid flow on either estimated permeability or extrapolated far-field fluid pressures been unambiguously determined. However, the general effect of borehole closure during pulse withdrawal testing of a discrete interval is to increase the measured fluid pressure (and hence both apparent fluid-flow rate and apparent permeability) above values calculated including the effects of closure.

Presently there are several uncertainties about the hydraulic characteristics of the Salado Formation: (1) the state of hydraulic saturation in the far field; (2) the driving forces for fluid flow, i.e., whether flow results from mechanical deformation, induced head gradients, or gas driven, two-phase behavior; and (3) the relevant flow paths, i.e., whether porous medium flow (including stratigraphic effects) or fracture flow is more important. These uncertainties affect the time scale of fluid flow and the rock mass volumes involved in flow for both short and long time scales.

As a result of these uncertainties, there are at present two general types of conceptual models for brine movement within the Salado Formation. One conceptual model, based on far-field Darcy flow (e.g., Bredehoeft, 1988; Nowak et al., 1988), assumes that (1) the Salado Formation is hydraulically saturated in the far field, although near-field effects may include formation of a local zone of two-phase behavior or partial saturation, and (2) fluid flow from the far field is the controlling or limiting process in the long term and can be modeled adequately using the Darcy equation, after accounting for stratigraphic effects and variability. In a Darcy formalism, fluid flow is directly proportional to the pressure gradient even when these gradients are very low. Even using such an approach, transient effects may extend over hundreds of years or more on the repository scale.

Other concepts for fluid movement within the Salado Formation are based on the interpretation that the concept of Darcy permeability within a sequence of layered evaporites such as the Salado Formation is valid only in those regions that have been significantly disturbed. In one such interpretation, the far-field permeability of the pristine halite is assumed to be essentially zero under any pressure gradient, i.e., undisturbed halite is assumed to have no interconnected porosity. By this interpretation, brine will flow into or out of the WIPP repository only in response to formation of a disturbed rock zone within which mechanical deformation is sufficient to generate interconnected porosity.

A less extreme but similar conceptual model assumes that there is some interconnected porosity within the Salado Formation even under undisturbed conditions. This model assumes that grain boundary fluids are so strongly bound that fluid flow only occurs under strong gradients, such as those generated near an underground excavation. With this model, fluid flow would take place in the near field even in the absence of mechanical disturbance. However, there would be no far-field fluid flow, due to the absence of sufficient gradients in this region.

The long-term or steady-state fluid inflow to the repository would decrease to zero by either non-Darcy conceptual model, possibly prior to complete saturation of the rooms and panels. Thus, either of the latter conceptual models may indicate that it is not necessary to assume that the repository will become hydraulically saturated in the long term, even in the absence of human intrusion.

Currently, it is not certain either that the different conceptual models of fluid flow within the Salado Formation have significantly different impacts to the long-term performance of the WIPP repository or that adequate measurements can be made in the field to distinguish between the models. All three conceptual models are consistent with the measurement of significant permeabilities within the disturbed rock zone and with observed transient flow behavior at relatively early times. In fact, preliminary calculations indicate that the volumes of brine collected to date may all come from within the present disturbed rock zone, even if modeled assuming Darcy flow. In general, interpretations assuming Darcy flow in the far field appear to be conservative, in that they do not result in an extrapolated zero flow rate at long times and do indicate maximum amounts of brine inflow.

From the viewpoint of long-term performance of the WIPP facility, the fundamental questions are whether (1) brine inflow into the disposal rooms will be sufficient to saturate backfill, waste, and the disturbed rock zone, either before or after compaction to the final mechanical state; and (2) the far-field permeability will be sufficient to dissipate brine and/or gas pressures at and near the final state, at some fluid pressure below lithostatic load.

2.3.3 Gas Generation in Waste Disposal Rooms

Microbial and radiolytic decomposition of the waste and corrosion of the drums could potentially lead to the generation of large amounts of gas. Pressurization of the disposal rooms may result if the rate of gas production exceeds the rate by which gas can be consumed in chemical reactions or migrate out of the disposal area. This pressurization could become a driving force for the release of radionuclides from the repository in the event of human intrusion.

Activities S.1.1.4, S.1.3.2, and S.1.3.3 and Appendix A of this Plan focus on the questions and studies directly related to gas generation and consumption within the repository. In summary, present knowledge concerning gas behavior within the repository suggests that

1. The total amount of gas generated within the repository by corrosion may be significantly greater than expected in 1980; however, the total estimated gas-generation potential is smaller than in 1980. Radiolysis of brine may also be a significant source of gas if the repository resaturates.

2. The addition of gas getters to the backfill should be considered for reducing the buildup of CO_2 and possibly H_2.

3. As a result of very low permeabilities and apparent far-field hydraulic saturation of the Salado Formation, gas transport rates from the disposal rooms into the undisturbed Salado Formation may be minimal at long times. This transport will be limited by solubility and diffusion, rather than by mass flow, thus giving rise to high gas pressures if gas generation rates are significant.

The combined impact of these changes is that gas generation, consumption, and transportation within the repository are extremely significant and are being reconsidered. At present, the limited data and combined uncertainties in net gas behavior result in broad uncertainty in the expected gas pressure history of the repository. If gas pressures exceed lithostatic pressure, these effects may

1. Result in gas-driven tensile fracturing of the Salado Formation in the near-field or far-field domains by generating pressures exceeding the least principle stress (near field) or lithostatic load (far field).

2. Stop structural closure at some porosity and permeability greater than that expected to occur in the absence of gas effects, by maintaining long-term gas pressures approximating the lithostatic load.

3. Result in a gas charged, one-phase fluid or a two-phase fluid system providing a driving force during human intrusion involving a single borehole.

4. Result in gases/brines escaping around seals or in VOCs acting to degrade seals.

5. Stop brine inflow.

If rigid structural members in the waste and the presence of a disturbed rock zone prohibit compaction to a final state of near-zero porosity, it may be possible to maintain a two-phase fluid system within the waste-filled rooms and disturbed rock zone at fluid pressures below lithostatic. The maintenance of a one-phase, gas-charged brine capable of providing a driving force in the event of human intrusion requires only that pressures greater than that of a column of brine extending to the surface be developed and maintained within the waste disposal facility.

Factors affecting gas generation rates and potentials include

1. The mass of cellulosic materials and nutrients (such as phosphate) available in the waste inventory for microbial degradation.

2. The relative oxidation state within the repository, as buffered by the combined effects of radiolysis and organic activity.

3. The masses of iron and aluminum in the waste inventory available for corrosion.

4. The volume of water (in the form of brine or water vapor) available for decomposition by anoxic corrosion, microbial activity, and radiolysis.

Modifications to the waste such as thermal treatment to oxidize the organics and metals can be performed if necessary to reduce the amount of gas that can be generated. Additional modifications to waste and/or backfill can be performed if necessary to reduce the initial void volume in the storage rooms to reduce brine inflow, thereby limiting gas generation from anoxic corrosion and radiolysis.

The currently planned gas-generation tests (Activities S.1.1.4, S.1.3.3, S.1.3.2; Appendix A) incorporate information on gas generation from the waste generators and will also collect similar information from the international community. Results of testing will be used to determine the need for and extent of additional measures to mitigate any potential adverse impacts associated with gas generation from the waste.

2.3.4 Shaft and Panel Seals

The goal for both shaft and panel sealing systems is to minimize migration of radionuclides from the waste disposal horizon into the surrounding environment. Many of the specifications for panel seals are directly applicable to shaft seals. The major difference between the two sealing systems is the host rock/seal interaction. All panel seals are contained within the Salado Formation while various units and a wider range of lithologies must be sealed in the shaft. These different lithologies affect the interaction of the seal and the host rock. As with the panel seals, the primary long-term sealing strategy for WIPP shafts is based on the reconsolidation of crushed salt to be emplaced in the Salado Formation at the lower section of the shafts (Stormont, 1988a; Tyler et al., 1988).

The evaluation of sealing materials and seal designs has been derived from laboratory and small-scale in situ testing, as well as from numerical modeling and analysis. The laboratory work has focused on sealing materials: crushed salt blocks and quarried salt, cementitious materials, and clays (primarily bentonite). For salt, laboratory and in situ studies have been directed toward understanding reconsolidation of crushed salt and the resulting fluid-flow properties. For bentonite, the density, swelling, and fluid-flow properties have been investigated. Laboratory and in situ test data indicate that bentonite-based seals will effectively restrict fluid flow over the short term. The long-term stability and integrity of salt and bentonite, as well as cement and cement/bentonite mixtures, have been the primary focus of laboratory investigations (Tyler et al., 1988). Large-scale, in situ seal tests are planned.

The long-term behavior of the sealing system's structure, fluid flow, and in situ interactions was modeled by numerical codes. These codes were based on preliminary laboratory data and were used to predict results of in situ tests. As in situ data became available, the codes were refined to more accurately reflect the physical processes and behavior.

In situ experiments have tested various sealing materials and designs under actual conditions. These experiments include permeability measurements of the various host or representative lithologies, tests of sealing systems representative of shaft seals, and evaluations of backfill and borehole plugs. These sealing tests have provided high quality thermal, structural, and fluid-flow data for candidate sealing materials in various configurations.

A comprehensive evaluation of shaft sealing materials, seal geometries, and locations within certain stratigraphic units has been completed (Stormont, 1988a). The factors evaluated include Rustler Formation hydrology, adjacent disturbed rock zone permeabilities, brine inflow in the Salado Formation, and shaft closure in the Salado. The reference design for seals in the Rustler is a concrete/bentonite composite. The reference design for Salado seals incorporates both multicomponent and reconsolidated, crushed salt seals. The primary material for sealing WIPP shafts is reconsolidated salt excavated from the waste disposal area. Although the WIPP reference shaft sealing system requires work to reduce uncertainty and corroborate the findings of the preliminary evaluations, no fundamental reason has been found to revise the design concepts (Tyler et al., 1988).

2.3.5 Hydrology and Radionuclide Transport Outside the Disturbed Rock Zone

Geologic and hydrologic site characterization activities at the WIPP facility have updated or refined the overall conceptual model of the geologic, hydrologic, and structural behavior of the WIPP site, with the objective of providing data adequate for use in performance assessment. A summary of the current conceptual model for geologic, hydrologic, and structural behavior of the WIPP site can be found in a report by Lappin (1988).

Two types of transient responses are occurring at and near the WIPP site: the continuing natural response of geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation approximately 12,000 to 16,000 years ago) in southeast New Mexico, and the continuing geologic responses to hydrologic, geochemical, and structural transients induced by WIPP site characterization and facility construction.

The Bell Canyon Formation (Figure 2-2) (largely shales, siltstones, and sandstones) contains the first relatively continuous water-bearing zone beneath the WIPP repository horizon. In some parts of the northern Delaware Basin, the unit contains permeable channel sandstones that are targets for hydrocarbon exploration. Recent studies suggest, however, that the upper Bell Canyon Formation at the WIPP site does not contain any major channel sandstone. These studies indicate that the final direction of fluid flow following interconnection of the Bell Canyon, Salado, and Rustler Formations would be downward into the Bell Canyon Formation, contrary to earlier assumptions. These observations indicate that the Bell Canyon Formation will not provide a source of fluids for contamination of the overlying Rustler Formation water-bearing units should a breach of the repository occur.

The Castile and Salado Formations, sequentially overlying the Bell Canyon Formation, are predominantly layered anhydrites and halites. Formation permeabilities in the Castile and Salado Formations remote from the WIPP excavations are generally less than 0.1 microdarcy. The low permeability of

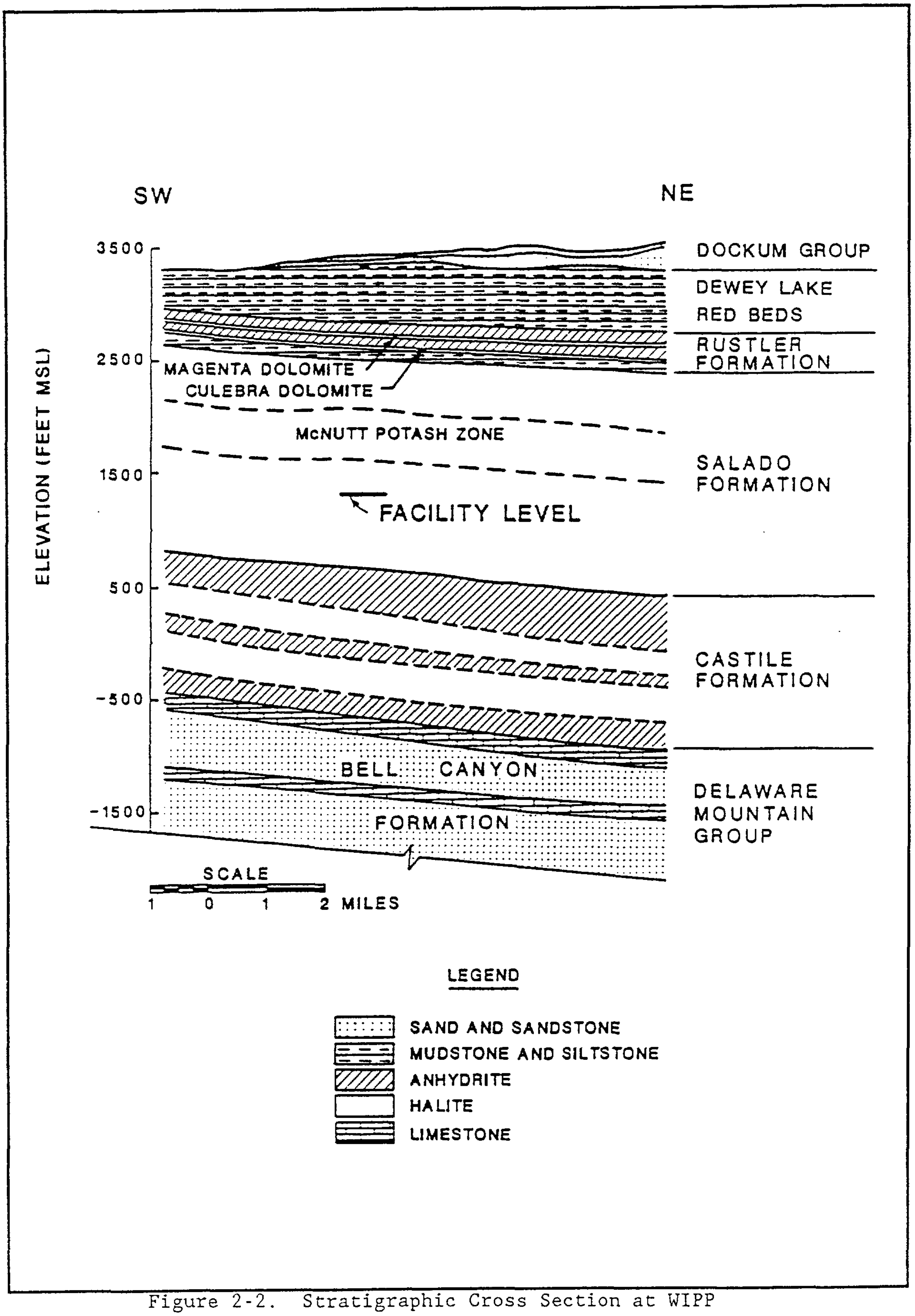


Figure 2-2. Stratigraphic Cross Section at WIPP

these two formations provides effective confining boundaries to fluid flow from the repository to water-bearing zones above and below the facility horizon.

Pressurized brines have been encountered in Castile Formation anhydrite in the WIPP-12, ERDA-6, and Belco boreholes (Popielak et al., 1983), north and south of the center of the WIPP site (Figure 2-3). Geophysical studies indicate that Castile Formation brines are probably present beneath a portion of the WIPP waste emplacement panels (Earth Technology, 1988), consistent with earlier assumptions. However, these brines are approximately 660 ft (200 m) or more below the WIPP facility horizon and are not of concern to long-term performance except in case of a human-intrusion breach of the facility.

The Rustler Formation is a layered unit of anhydrites, siltstones, and halites containing two variably fractured carbonate units, the Culebra and Magenta Dolomite Members. The Culebra Dolomite is the first continuous water-bearing unit above the WIPP repository horizon and is at least an order of magnitude more permeable than other members of the Rustler Formation, including the Magenta Dolomite. As a result, the Culebra Dolomite dominates fluid flow within the Rustler Formation at the WIPP site and is the most significant pathway to the accessible environment from the WIPP repository except for direct breach to the surface. Culebra Dolomite transmissivity varies by approximately six orders of magnitude in the region containing the WIPP site, ranging from 2.15×10^{-9} meters^2/second to 1.34×10^{-3} meters^2/second (Lappin, 1988). Culebra Dolomite transmissivity in the central portion of the site, including all four WIPP shafts, is low; higher Culebra Dolomite transmissivities are found in areas to the southwest, southeast, and northwest.

In the WIPP site area, modern flow in the Culebra Dolomite Member is confined and largely north to south. However, fluid flow and geochemistry within the Culebra Dolomite and shallower units are in continuing transient response to the marked decrease or cessation of localized recharge at approximately the end of the last pluvial period. Both bulk chemistry and isotopic relations of Culebra Dolomite fluids are inconsistent with modern flow directions if steady-state, confined flow is assumed. It is assumed that recharge to the Rustler in the past occurred within Nash Draw, with resultant flow generally to the east and southeast. Flow is interpreted to have reoriented to its present general southerly direction in response to the end of recharge. This interpretation of the change in flow directions within the Rustler is based largely on uranium-disequilibrium studies (Lambert and Carter, 1987). Because of the relative head potentials within the Rustler Formation at and near the WIPP site, there appears to be a small amount of vertical fluid flow between its members, even though the permeabilities of Rustler Formation members other than the Culebra Dolomite are quite low. Where measured successfully, the modern head potentials within the Rustler Formation prevent fluid flow from the surface downward into the Rustler carbonates. These results suggest that recharge from the surface to the Rustler Formation is not occurring at the WIPP site. Deuterium-oxygen analyses available from the Rustler Formation consistently indicate an isotopic character distinct from that of modern meteoric precipitation in the area (Lambert and Harvey, 1987). The results of stable isotope, radiocarbon, and uranium disequilibrium studies are also consistent with the interpretation of no measurable modern recharge to the Culebra Dolomite from the surface at or near the WIPP site.

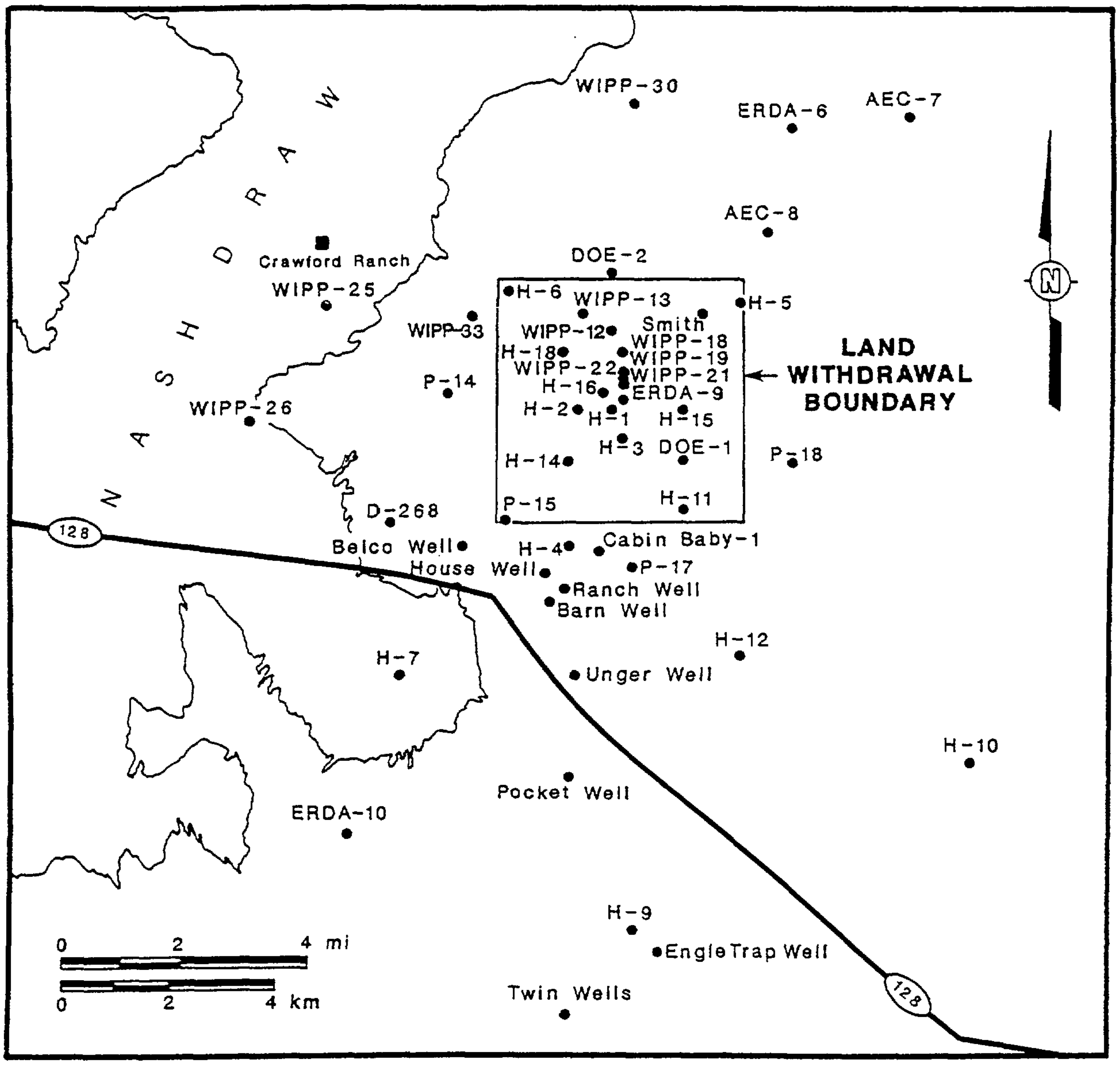


Figure 2-3. Hydrologic Test Wells near WIPP

Within and near Nash Draw, evaporite karst processes operate within the Rustler Formation, as evidenced by the continuing development of small caves and sinkholes in near-surface anhydrites and gypsums of the Forty-niner and Tamarisk Members. There is no evidence of karstic hydrology in the Rustler Formation at the WIPP site. However, fracturing of some portions of the Culebra Dolomite is sufficient at the site to strongly affect both hydraulic and transport behavior over distances of approximately 100 ft (30 m). Detailed transport calculations and ground-water flow modeling indicate that fracturing effects are not significant in regional-scale transport within the Culebra Dolomite, as long as the modern head distribution is not significantly disturbed.

The Dewey Lake Red Beds overlying the Rustler Formation consist largely of siltstones and claystones, with subordinate sandstones. In tested locations, the Dewey Lake Red Beds are too low in permeability for successful hydrologic testing. At the WIPP site the Dewey Lake Red Beds are unsaturated, but less than 1/2 mi (1 km) south of the WIPP site boundary, sandstones within the Dewey Lake Red Beds produce potable water. Isotopic relations suggest that surficial waters have contributed to the formation of secondary gypsum veins within the Dewey Lake Red Beds, but that the Dewey Lake Red Beds and Rustler Formation hydrologic systems are not currently well connected. Limited strontium isotope studies of the Rustler Formation and Dewey Lake Red Beds appear to indicate limited vertical fluid flow from the Rustler upward into the Dewey Lake Red Beds and a major involvement of surficial materials in crystallization of secondary veins within the Dewey Lake Red Beds (Lambert, 1988). Similar studies, again based on limited data, indicate that secondary gypsum veins within the Rustler could not have crystallized in equilibrium with modern meteoric recharge in the area.

In addition to the geologic and hydrologic characteristics of the disposal system, radionuclide transport calculations require a source term, i.e., a description of the quantities, species, and rates of radionuclides available for transport. The chemical behavior of the important radionuclides in TRU waste in WIPP brine must be predicted to define the source term.

Laboratory studies provide a unique opportunity to develop a mechanistic understanding of repository and radionuclide chemistry. Because chemical reactions can produce or consume large quantities of gas and water, studies of these reactions are necessary to predict their effects on repository gas and water budgets. The gas and water contents of the repository could affect room-closure rates, geomechanical properties of the room contents, and the likelihood of radionuclide release. Various chemical reactions can also affect the Eh and pH of any brine present in the rooms; these parameters will in turn influence the solubilities of certain gases in the brine and the speciation, solubilities, and sorption of radionuclides. Laboratory studies will be used to quantify the effects of significant processes under conditions that isolate the processes from each other, yet are nevertheless realistic, and to determine the effects of variations in repository chemistry on these processes. Modeling studies will be used to extend the results of laboratory studies to other conditions and to simulate the complex interactions between the processes studied in the laboratory.

2.4 OVERVIEW OF TECHNICAL APPROACH FOR COMPLIANCE WITH 40 CFR 191, SUBPART B

2.4.1 Performance Assessment

In 1986, the Project reviewed the performance assessment activities, the regulatory requirements, and the methodology developed at Sandia National Laboratories for the Subseabed Disposal Project and for the Nuclear Regulatory Commission (NRC) and EPA regulatory development programs. The outcome of the review was a decision for the performance assessment to use proven conceptual methodology rather than develop a new methodology. The Standard suggests that if another methodology is used, different from the NRC/EPA conceptual methodology, comparisons of the new methods with those used to develop the NRC/EPA methodology would have to be made. The NRC/EPA methodology, documented by Hunter et al. (1986), was selected.

Using this methodology, the first step was to develop and begin screening the scenarios that will guide the performance evaluation. The next step was to develop tools allowing the conceptual performance assessment methodology to be used in an actual performance assessment. The main undeveloped computational tool was an executive code that would control, track, and store for future reference all parts of each calculation for each scenario. Earlier work by the Subseabed Disposal Project and NRC/EPA groups identified human error in translation between different subcodes within a given scenario as a major failure mode. An executive code, CAMCON, has been developed to remove most, if not all, of the possible human errors (Rechard, 1989).

The performance assessment methodology presented here is a complex process comprising seven major components: (1) data collection, model development, and engineered alternatives, (2) scenario development and screening, (3) preliminary consequence analysis, (4) sensitivity and uncertainty analysis, (5) final consequence analysis and comparison with the EPA Standard, (6) analysis of undisturbed performance, and (7) documentation. The interrelationships between these components are shown in Figure 2-4 and are briefly described below; a more complete description can be found in Bertram-Howery and Hunter (1989b).

Data Collection, Model Development, and Engineered Alternatives: Consequence modeling requires the development of conceptual models, which are geologic and hydrologic descriptions of the region surrounding the WIPP and descriptions of the repository, derived from disposal system characterization data. The activities that provide this information are described in Section 2.7.2, beginning on p. 2-90. Because WIPP site characterization and repository design have been underway since 1975, the observational data base is large. These programs have also developed several numerical models that will be incorporated into the performance assessment computational methodology. An important component of the methodology is the development of accepted regional and local hydrologic and material-transport models that describe the movement of water and dissolved waste through the site. The upper aquifer, regional, fluid- and material-transport model has been developed and tested, and a description of the code is currently in preparation (Brinster, 1989).

Characterization of the disposal system and the surrounding area and development of models will continue during the Test Phase, both to support the performance assessment and to complete the disposal facility conceptual design. The existing data base will be expanded to support a larger, regional conceptual

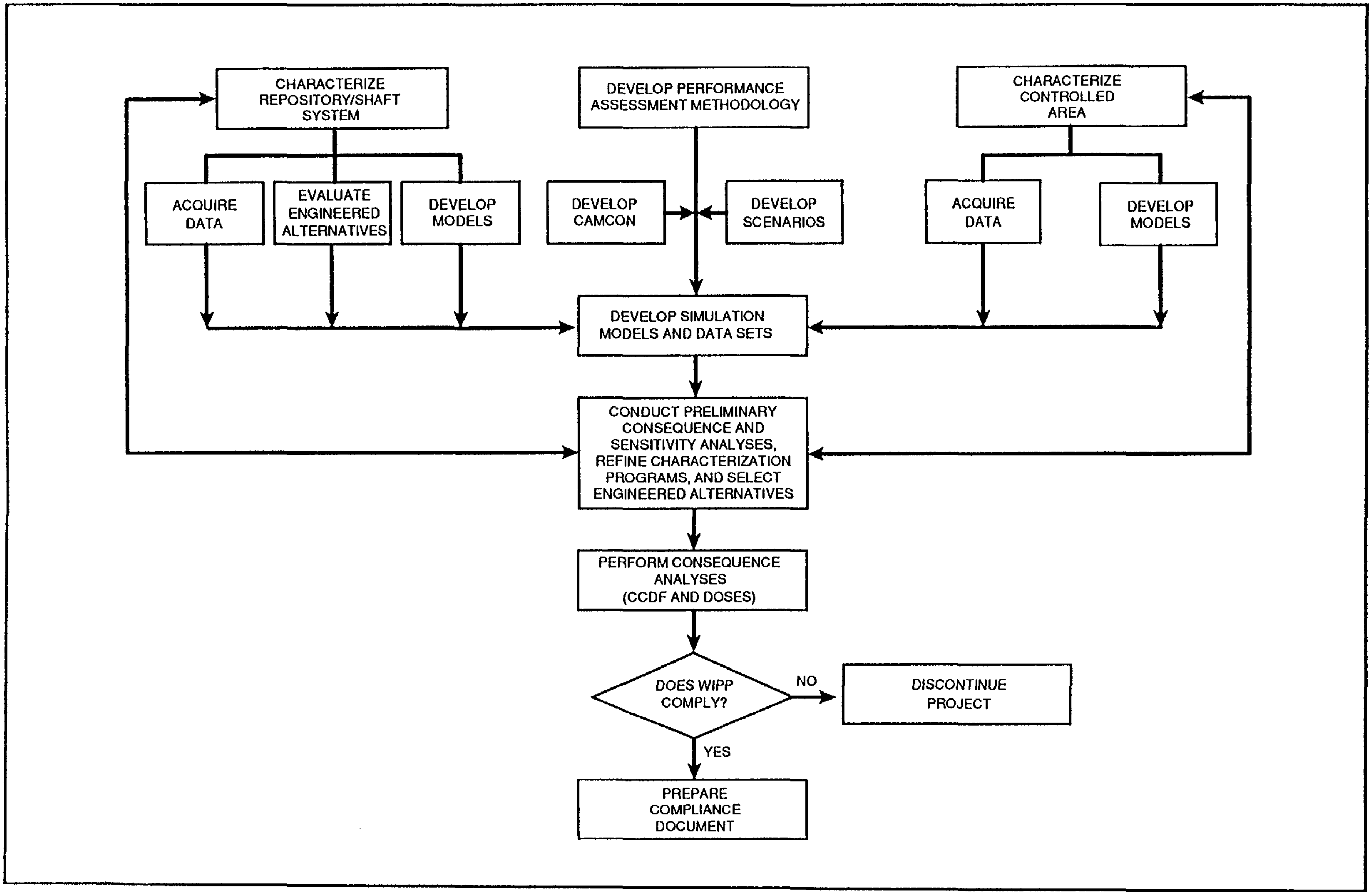


Figure 2-4. Flow Chart of the Performance Assessment Process

model domain for performance assessment. This expansion includes gathering and synthesizing additional geologic and hydrologic data for the selected domain and for outlying regions that may influence this domain. The data base will also be expanded to include more specific data on the backfill performance and salt creep closure. It also will include the conceptual design of the seals and data on gas generation. The disposal system characterization activities provide most of this component of the performance assessment methodology. If no data or sparse data are available for a given parameter, performance assessment will use the best available estimates of the parameter's range and distribution and perform appropriate sensitivity analyses to determine the effect of the parameter uncertainty on the results for each affected scenario. The uncertainty in the parameter may be larger than would be the case if the information were better characterized.

If preliminary performance assessment calculations indicate a potential for uncertain or unsatisfactory performance, it may be necessary to implement modifications to the waste forms or to the reference disposal system design. The effort to be prepared to implement these modifications is currently underway (Activity S.1.2.5; Arthur, 1989) and consists of three parts: model development, design analysis, and engineered alternatives feasibility evaluation. An integrated deterministic model is under development that will include room, shaft, and far-field models; it will be capable of simulating both natural processes and human intrusion scenarios. A routine will be included that evaluates releases of radioactive and hazardous constituents from the disposal system. The final deterministic model will be used to highlight any potential problems with regulatory compliance and to evaluate the relative effectiveness of proposed modifications to the current design. Additional information needs and any recommended experimental programs will be identified where appropriate. In addition, appropriate alternatives will be tested in bin-scale and alcove tests to demonstrate their effectiveness in mitigating the problems they are designed to alleviate. These final recommendations will then be evaluated using the formal performance assessment process to quantify the improved performance of the disposal system.

Scenario Development and Screening: Preliminary estimates of consequences can also be used to screen out scenarios, if their omission is not expected to change the remaining probability distribution of cumulative releases significantly. In addition, events, processes, and scenarios can be screened out if they are physically unreasonable or not of regulatory interest. Finally, scenarios can be omitted, or screened out, from the performance assessment if the probability of occurrence is less than 1 in 10,000 in 10,000 years. Establishing the probability of occurrence of scenarios is therefore necessary to show compliance with the Standard. The events retained for further WIPP scenario development include the effects of a pressurized brine occurrence beneath the WIPP, climatic change, dissolution of waste or rock immediately adjacent to the repository, drilling into the repository, ground-water flow, the effects of mining for resources, seal performance, subsidence of overlying rock into the repository, waste/rock interaction, and waste effects.

The methodology for scenario development and screening continues to evolve during the WIPP performance assessment. For earlier deterministic assessments for the WIPP Program, scenarios have been developed using flow diagrams. For probabilistic assessments, changes in the amount of rain at a site, for example, would be handled in the range and distribution of the parameters in that process and thus would not lead to multiple scenarios. Because 40 CFR 191 is the first waste management standard to require a probabilistic methodology, early scenario development work for the WIPP performance assessment produced lists of scenarios that had mixed sets of branch points (Bingham and Barr, 1979).

With the different types of regulations needing different types of scenarios the word scenario should not be used without qualification. Scenarios developed for deterministic calculations differ from those for a probabilistic analysis in that they must include both the event or process and the data ranges. For probabilistic analysis the data ranges are not included in the scenario.

Currently, the events and processes identified as important by Hunter (1989) are being used to prepare a set of probabilistic scenarios (Guzowski, 1990). These will be reviewed for completeness and clarity of type of scenario at each branch point within the flow diagram.

Supplements to the scenario development report will contain the results of scenario screening and will incorporate or respond to any comments from outside organizations and individuals. If it is necessary to develop or expand scenarios because of new data, these new scenarios will be reported in the supplements.

Preliminary Consequence Analyses: The preliminary consequence analysis will assemble and test the entire suite of codes, models, and techniques necessary to prepare a complementary cumulative distribution function (CCDF) that indicates the probability of exceeding various levels of cumulative release for comparison with the Standard. If the performance assessment methodology is found to be deficient during the preliminary analyses, these deficiencies will be corrected before the final consequence analysis is performed. Scenarios that survive the screening will be analyzed. Regional and local hydrologic models will be used to examine ground-water flow under the various scenarios. Codes appropriate for simulating the transport of radionuclides through geologic formations will be selected. Models provided by various disposal system characterization activities will be assembled and adapted into the model of the repository/shaft system, which will comprise linked codes for models of the rooms, panel seals, drifts from the panel seals to the shafts, and shafts and seals.

Effects of uncertainty in scenario probabilities will be examined and potential problems identified during the preliminary consequence analysis. A determination of the need for dose calculations can also be made at this stage. The complementary cumulative distribution functions calculated during this preliminary work will be incomplete. In some cases, data will be insufficient and the Project will still be carrying out important sensitivity analyses to design scenario-dependent computational strategies. Preliminary consequence analyses will be subject to continuous internal peer review. Semiannual briefings on the results of the preliminary consequence analyses will be presented to EPA, NAS/NAE, the State of New Mexico, and the EEG. The results will be documented annually and issued externally.

The WIPP methodology will be implemented using a modular system of computer codes referred to as the "compliance assessment system." The complex disposal system at the WIPP requires that the series of computer codes in the compliance assessment system be controlled by an executive software package, CAMCON (Compliance Assessment Methodology CONtroller; Rechard, 1989). CAMCON minimizes analyst intervention and automatically handles quality assurance during the calculational process. The primary data base comprises the analyzed, strictly quality-assured data for performance assessment purposes. The primary data base must be interfaced with CAMCON by objectively or subjectively extending it to regular grid information. These new data files will be placed into the secondary data base where they may be directly accessed by the various model components of CAMCON. The preliminary consequence analysis will set up the entire calculation sequence, using CAMCON and the appropriate data bases, for each significant scenario.

Sensitivity and Uncertainty Analysis: Sensitivity analyses will be performed for each scenario that appears to be of regulatory interest as part of the preliminary consequence analysis. Figure 2-4 shows sensitivity analysis as an iterative step preceding consequence analysis. The main function of sensitivity analysis is to determine the relative importance of the parameters that provide input to the consequence analysis. This information provides guidance to the Performance Assessment Program in the following ways:

Identifying the critical input parameters. Determine the critical input parameters at both the system and subsystem levels. Sensitivity analysis of the computational system for a scenario helps identify those parameters that are important in modifying the response of a model segment and those model segments that are important in modifying the response of the system. These input parameters or model segments are then analyzed in greater detail to see how they are changing. For those components which are changing in a nonlinear manner, more precise values will be needed for both the parameter range and the distribution.

Determine the relative importance of data collection activities. As the relative importance and required accuracy of input parameters are determined, sensitivity analysis provides the opportunity to upgrade or downgrade the priorities of data collection activities. This prioritization will provide direction to the Project for more efficient use of finite resources and expertise.

Provide guidance to the development of design enhancements. If it is determined that a critical parameter needs to be known to an accuracy that is beyond the capabilities of the current technology, design modifications may be employed to lessen the importance of that parameter on the long-term performance. For example, if it is determined that brine inflow rates cannot be established with sufficient confidence to be within an acceptable range, compaction of the waste and the use of a grout backfill could greatly reduce the time required for the rooms to close and thus reduce the quantity of brine expected to flow into the room.

Sensitivity analysis for a given scenario begins with a description of a conceptual model of the disposal system. The best available computational models and required input data for each affected subsystem are then assembled to simulate the response of the disposal system to the scenario. Response, or performance, is usually measured in terms of either potential doses to individuals over a 1,000-year interval, or as 10,000-year cumulative releases of individual radionuclides. Key input parameters are then varied over some reasonable range of values to determine the effect of varying these parameters on the consequence of the scenario. Poorly defined parameters that are shown through sensitivity analysis to have a strong effect on performance are highlighted as key parameters. Activities that provide accurate and defensible values for these key parameters will be given a high priority. Activities that provide values for parameters that are shown to be less critical to performance will be downgraded to a lower priority. The results of ongoing sensitivity analyses will be subject to peer review and will be documented annually.

A number of sensitivity analyses have been used in the past to determine the nature of the critical risks and issues at the WIPP (Anderson et al., 1990), primarily by determining their effects on the safety of the repository. The promulgation of the EPA Standard shifted the emphasis of the assessments from safety to compliance with the Standard, that is, from doses to releases and from the Pecos River to the controlled area. Initial sensitivity analyses in direct support of the performance assessment (Lappin et al., 1989) revealed that brine-influx rates, radionuclide solubility, radionuclide inventory, and initial void volume were critical parameters to be understood before compliance with the Standard could be demonstrated. Four energy sources were identified that could move waste from the repository horizon to the accessible environment: drilling equipment and fluids, gravitational effects, gas generation and entrainment within the rooms or panels, and the pressurized brine occurrence below the repository. At about the same time, in-situ experiments revealed that the permeability of the Salado Formation is a few orders of magnitude less than had been thought based on above-ground testing. Analyses of the new data showed that gas-generation rates and volumes are also critical.

Further analysis may show that the performance of the disposal system is insensitive to some parameters that are now being investigated; unfortunately, it is difficult to determine in advance of the complete analysis which of the parameters these might be. In the near term, the technical and scientific programs of the WIPP Project will continue to perform sensitivity analyses to provide some guidance on the most important parameters in the overall risk-assessment model and will use these analyses as a guide in establishing program priorities. Some activities may eventually be terminated, but experience has shown the risks associated with prematurely terminating an investigation before the whole assessment is complete. For example, initial work on gas generation was performed about 10 years ago, but was terminated because the rock permeabilities were believed to be higher than they are now known to be, and it was thought that no high gas pressures could develop.

A method has been developed to use sensitivity analysis in conjunction with the generation of preliminary complementary cumulative distribution functions (CCDFs) to determine the effects of individual parameters, scenarios, and subsystems (e.g., disposal room) on potential compliance with 40 CFR 191. For example, trial calculations have examined the potential effects of changes in waste solubility, porosity, permeability, and hydraulic conductivity on releases arising from selected scenarios. These calculations have shown that by varying values of these parameters over selected ranges hypothetical releases may be either above or below the release limits set by 40 CFR 191. Similar calculations will be used in the future to focus experimental programs and examinations of engineered alternatives on critical subsystems, scenarios, and parameters.

Three studies to be published early in 1990 will illuminate the rationale for the current program. A "history of the sensitivity analyses" (Anderson et al., 1990) will identify past studies that have used optimization and other techniques throughout the lifetime of the WIPP Project to identify the most significant parameters for topics of research and development. New sensitivity analyses (Marietta et al., 1990; Rechard et al., 1990) are also scheduled to be completed early in 1990. These and other sensitivity analyses will be used to further assign priorities to the extent feasible and prudent.

Uncertainty analysis determines the uncertainty in the performance-measure calculation resulting from uncertainty in scenarios, models, and input data. The WIPP Project will address scenario uncertainty through external peer review. Uncertainty in the models will be addressed through verification, validation, calibration programs, and quality assurance. Uncertainty in the input data will be incorporated by Monte Carlo sampling. The Standard requires that the performance assessment results be incorporated into an overall probability distribution of cumulative release to the extent practicable. Appendix B of the Standard suggests that the results be assembled into a single complementary cumulative distribution function that indicates the probability of exceeding various levels of cumulative release. This single curve will incorporate all parameter uncertainty. If this single distribution function meets the release limits, then a disposal system can be considered to be in compliance with the Containment Requirements. Uncertainty analysis is an integral part of consequence analysis.

<u>Final Consequence Analysis and Comparison with Standard</u>: Final consequence analysis will be performed for each scenario determined to be significant during the scenario-screening process. It will be performed using the performance assessment methodology described for the preliminary consequence analysis, modified as necessary to correct any deficiencies found during that earlier analysis. The results of the final analysis will be assembled and presented in the form of a complementary cumulative distribution function, which will be compared with the Standard. This activity comprises several tasks: finalizing all data and models, simulating all scenarios through CAMCON, analyzing each scenario's results, producing the final complementary cumulative distribution function, and comparing the complementary cumulative distribution function with the Standard.

<u>Analysis of Undisturbed Performance</u>: If any release of radionuclides from the undisturbed scenario during the first 1,000 years is projected by the final consequence analysis, annual doses will be calculated and compared with 40 CFR 191, Section 15, Individual Protection Requirements. Releases to the accessible environment are not expected during that time, so dose calculations should not be necessary; however, the WIPP Project will be prepared to perform such calculations. The Project intends to use the compliance assessment system in demonstrating compliance with the Individual Protection Requirements. A scenario describing the undisturbed performance of the repository will be simulated using reasonable projections of the expected behavior of the repository. Release calculations for the undisturbed scenario will use CAMCON models to determine the need for dose calculations. Pathways and dosimetry models and corresponding data bases will be included in CAMCON.

<u>Documentation</u>: DOE is currently responsible for determining whether WIPP complies with Subpart B of the Standard. That determination will be based on a

document that describes the compliance evaluation process and compares the disposal system performance with the Standard. A report to be issued late in 1989 (Bertram-Howery et al., 1989) will be a preview of the 1993 Draft EPA (40 CFR 191) Compliance Report, having the same format, table of contents, and, where available, text. A second document (Marietta et al., 1989) will present the methodology to be used in the final performance assessment for external review of format and scope by the EPA, NAS/NAE WIPP Panel, State of New Mexico, and EEG. Where final text is not yet available, the 1989 texts will be annotated outlines of the final texts. These documents will be revised annually to incorporate the results of the iterative performance assessment calculations. The 1993 document will include descriptions and results of the final consequence analysis and the complementary cumulative distribution function for the Containment Requirements (Section 13) and dose estimates for the Individual Protection Requirements (Section 15). It will also address the Assurance Requirements (Section 14) and the Ground Water Protection Requirements (Section 16). The 1993 document will reflect the final form of 40 CFR 191, Subpart B, if it has been promulgated.

2.4.2 Technical Support

The technical approach for the WIPP disposal system characterization has been and continues to be a systematic process that will obtain sufficient technical information for establishing a design basis for waste isolation and for performance assessment of the disposal system. Five major processes have been identified that will ultimately provide a level of confidence that the data base is adequate:

- Laboratory Testing and Model Development including theoretical analysis and the determination of physical and chemical properties of materials.
- Site Characterization including geology, hydrology, geochemistry, and geophysics.
- In Situ Testing including the acquisition of data from full-scale tests underground, in some cases using actual waste.
- Data Reduction and Analysis including the feedback process of comparing in situ and field data with predictions.
- Evaluation and Validation including the adjustment and refinements of theoretical models and techniques to predict long-term behavior that would be expected in the host rock.

Laboratory testing and model development for waste isolation have been continuing efforts of the WIPP Project since 1975. These efforts include extensive model development, theoretical analysis, and laboratory testing. Depending on the technical issue being addressed, model development can be associated with a laboratory, material property testing program, or with a theoretical study of mechanisms, physical and chemical processes, or fundamental static or dynamic laws. Laboratory testing and theoretical studies are performed in an appropriate sequence or in parallel to evaluate the adequacy of the model to represent the phenomenon in question. Laboratory testing and theoretical analyses are usually conducted as complementing efforts so that when complete, a predictive model can be used to represent material behavior or response of a physical/chemical process.

Site characterization activities have been underway since 1975. The overall conceptual model of the geologic, hydrologic, and structural behavior of the site has been developed and refined. Site characterization is nearly complete.

In situ testing with and without radioactive wastes is necessary to validate design concepts and models to be used for performance assessment. Although models and theoretical developments can be evaluated in part by laboratory or bench-scale experiments, in situ testing has been considered a vital part of the WIPP for

- Providing the basis for establishing a level of confidence in models by validation with data from in situ tests.
- Establishing designs and systems concepts including appropriate performance criteria.
- Demonstrating the developed technology for scientific and public scrutiny and acceptance.

In situ testing for waste isolation is limited for practical reasons because it cannot in all situations accurately simulate effects over large areas (repository size) nor can it directly address long-term effects. Configurations for the in situ tests at WIPP are therefore linked with theoretical techniques so that test results can then be used to evaluate the capability to predict response through the testing period and 10,000 years into the future.

In situ tests at WIPP have been configured to measure a wide range of parameters that are used in models and data developed from laboratory studies. These models and the information obtained from numerous studies are also used in calculations that determine the scope, configuration, and measurement location of the individual in situ tests. Calculations, normally completed prior to initiating a test, establish reference predictions of the proposed test and develop a format against which a direct comparison can be made with in situ measurements. This comparison between model prediction and in situ measurement then forms the basis for data analysis and evaluation studies.

Data reduction and analysis must ensure quality control while large numbers of data are managed in an efficient and effective manner. The data reduction portion of the process provides a systematic procedure developed appropriately for (1) screening the raw data, (2) reviewing it for missing information, (3) making appropriate corrections and adjustments for time shifts or calibrations based on the judgment of the principal investigators, (4) evaluating and analyzing the corrected data for consistency based on comparisons with similar measurements or expected physical or chemical responses, and (5) presenting the information in data reports for subsequent analyses.

Evaluation and validation examine analyzed, in situ data and compare them with early laboratory data and theoretical studies. Many of the chemical- and radioactive-interaction, fluid-flow, material-property, and constitutive models will be evaluated against in situ behavior of material components and systems. Adjustments to computer codes and analytical techniques will be made if necessary so that the predictive procedures will more closely represent actual behavior.

2.5 DESCRIPTION OF THE PERFORMANCE ASSESSMENT PROGRAM

The program for determination of compliance with 40 CFR 191, Subpart B, is divided into elements and activities. The elements provide a framework that defines the type of information and data that is necessary to evaluate compliance with the Standard. Activities describe the specific tasks that will provide the data needs identified in the elements.

The elements are presented in a hierarchy that illustrates the logic of the data needs for performance assessment. The hierarchy is presented in Table 2-1. There are five basic elements: (1) scenario screening, (2) repository/shaft system behavior, (3) controlled area behavior, (4) computational system development, and (5) consequence analysis. These elements are further divided into more specific data needs, which are presented as subelements. Each subelement, in turn, develops the more detailed information needs.

The information needs mentioned above define the activities that will be performed. There are two basic sets of activities described in Section 2.7: (1) performance assessment, and (2) supporting (disposal system characterization) activities. The performance assessment activities focus on the scenario development and modeling that will be used to predict the consequences of credible processes and events that could potentially lead to releases of radionuclides from the disposal system. Disposal system characterization activities focus on obtaining the data and understanding necessary to provide input to the performance assessment models.

The procedural approach to predicting performance is based on the guidance provided by the EPA with the Standard. Although this is not the only possible approach, it is based on techniques used by the EPA to evaluate the feasibility of the Standard itself. For the 10,000-year performance, the EPA has indicated that the predicted releases from all simulations for all scenarios analyzed will be combined with the scenario probabilities and presented in one complementary cumulative distribution function. This single function will be compared with the release limits set by the Standard. For the 1,000-year performance, the annual release distribution for each release location is used to calculate an annual dose distribution. The EPA has indicated that the mean or the median of each dose distribution will be used for comparison with the dose limits.

These analyses will require that the behavior of the entire system be adequately simulated to determine compliance, and that certain components of the system also be simulated separately. For example, the undisturbed performance will require simulation of the entire system, while certain human-intrusion scenarios will require simulation of intrusion into a room and subsequent transport in the Culebra Dolomite Member of the Rustler Formation. Some scenarios, such as intrusion into a pressurized brine occurrence, may require specialized models. The assessment elements address the scenario analysis, the assembly of appropriate subsystem and system computational models to describe conceptual models for each scenario, the complexity of the computational system, and the calculation of releases and doses. Assembly of the models requires characterization of the total disposal system, including the behavior of the repository and shaft system and the potential for hydrologic transport of radionuclides beyond the repository and shaft system.

Table 2-1. Work Elements, Subelements, and Information Needs For Performance Assessment

Element 1.1
Scenario Screening

Subelement 1.1.1 Climatic Change
- 1.1.1.1 Modern Hydrology
- 1.1.1.2 Paleoclimatology/Hydrology
- 1.1.1.3 Recharge

Subelement 1.1.2 Nuclear Criticality
- 1.1.2.1 Radionuclide Inventory
- 1.1.2.2 Radionuclide Distributions and Concentrations
- 1.1.2.3 Reconcentration

Subelement 1.1.3 Human Intrusion
- 1.1.3.1 Flow Direction in Deeper Geologic Formation Boreholes
- 1.1.3.2 Room Effects
- 1.1.3.3 Deeper Geologic Formation Flow
- 1.1.3.4 Culebra Dolomite Hydrology
- 1.1.3.5 Two-Borehole Effects
- 1.1.3.6 Subsidence Zone
- 1.1.3.7 Flow Variations

Subelement 1.1.4 Seal Performance
- 1.1.4.1 Seal Performance
- 1.1.4.2 Failure Modes

Subelement 1.1.5 Probability Assignment
- 1.1.5.1 Scenarios
- 1.1.5.2 Expert Opinion
- 1.1.5.3 Probabilities

Element 1.2
Repository/Shaft System: Behavior Characterization and Performance Modeling

Subelement 1.2.1 Waste Disposal Room Behavior and Modeling
- 1.2.1.1 Source Term
- 1.2.1.2 Backfill
- 1.2.1.3 Container Response
- 1.2.1.4 Closure
- 1.2.1.5 Brine Inflow and Room Resaturation
- 1.2.1.6 Gas Generation and Behavior
- 1.2.1.7 Disturbed Rock Zone
- 1.2.1.8 Systems Interactions
- 1.2.1.9 Disposal Room Design

Subelement 1.2.2 Panel Seal Behavior and Modeling
- 1.2.2.1 Disturbed Rock Zone and Fluid-Flow Characteristics
- 1.2.2.2 Sealing System
- 1.2.2.3 Closure
- 1.2.2.4 Sealing Criteria, Concepts, and Designs

Subelement 1.2.3 Access Drift Behavior and Modeling
- 1.2.3.1 Backfill
- 1.2.3.2 Disturbed Rock Zone
- 1.2.3.3 Closure

Subelement 1.2.4 Shaft Seal Behavior and Modeling
- 1.2.4.1 Backfill
- 1.2.4.2 Sealing System
- 1.2.4.3 Disturbed Rock Zone and Fluid-Flow Characteristics
- 1.2.4.4 Closure
- 1.2.4.5 Sealing Criteria, Concepts, and Designs

Subelement 1.2.5 Transport Modeling
- 1.2.5.1 Subdomains
- 1.2.5.2 Transport Mechanisms
- 1.2.5.3 Transients
- 1.2.5.4 Transport Codes
- 1.2.5.5 Optimization

Element 1.3
Controlled Area: Behavior Characterization and Performance Modeling

Subelement 1.3.1 Los Medanos Regional Flow Modeling
- 1.3.1.1 Culebra-Magenta
- 1.3.1.2 Dewey Lake Red Beds
- 1.3.1.3 Culebra
- 1.3.1.4 Fluid Density
- 1.3.1.5 Regional Boundary Conditions
- 1.3.1.6 Recharge
- 1.3.1.7 Extent of Dissolution

Subelement 1.3.2 Controlled Area Flow Modeling
- 1.3.2.1 Salado Formation
- 1.3.2.2 Culebra Dolomite Member
- 1.3.2.3 Rustler/Salado Formation
- 1.3.2.4 Rustler Formation
- 1.3.2.5 Dewey Lake Red Beds
- 1.3.2.6 Rustler/Dewey Lake Red Beds
- 1.3.2.7 Castile Formation Brines
- 1.3.2.8 Pressurized Brine Hydrofracturing and Transport
- 1.3.2.9 Bell Canyon Flow and Geochemistry
- 1.3.2.10 Optimization
- 1.3.2.11 Composite Domain

Subelement 1.3.3 Hydrologic Transport Modeling
- 1.3.3.1 Subdomains
- 1.3.3.2 Transport Mechanisms
- 1.3.3.3 Transients
- 1.3.3.4 Transport Codes
- 1.3.3.5 Optimization

Subelement 1.3.4 Borehole Plug Behavior and Modeling
- 1.3.4.1 Borehole Plugging Material Behavior
- 1.3.4.2 Borehole Plug Interactions
- 1.3.4.3 Borehole Plugging Criteria, Concepts, and Designs

Element 1.4
Computational System

Subelement 1.4.1 Development of the Compliance Assessment System
- 1.4.1.1 Computer Codes
- 1.4.1.2 Variable Mesh
- 1.4.1.3 Vertical Resolution
- 1.4.1.4 Diagnostics
- 1.4.1.5 Sampling
- 1.4.1.6 Translators

Subelement 1.4.2 Compliance Assessment Data Bases
- 1.4.2.1 Primary Data Assembly
- 1.4.2.2 Primary Data Interpretation

Element 1.5
Consequence Analysis

Subelement 1.5.1 Containment Requirements
- 1.5.1.1 Scenarios and Probabilities
- 1.5.1.2 Conceptual Models
- 1.5.1.3 Computational Models
- 1.5.1.4 Release Simulations
- 1.5.1.5 Complementary Cumulative Distribution Function

Subelement 1.5.2 Individual Protection Requirements
- 1.5.2.1 Scenario
- 1.5.2.2 Conceptual Model
- 1.5.2.3 Computational Model
- 1.5.2.4 Release Simulations
- 1.5.2.5 Pathway Simulations
- 1.5.2.6 Doses

The Performance Assessment Program will be considered complete when

- The complete set of significant scenarios with probabilities of occurrence has been defined and the corresponding set of disposal system conceptual models described.
- Each conceptual model can be adequately simulated by a system of optimized computational models using appropriate, well-defined data sets.
- The data sets have undergone quality assurance and the computational models and systems of models have been verified and validated to the extent possible.
- The computational system is operational and record keeping is adequate to support repetition or modification of each simulation.
- The final analyses and comparisons to the release limits and dose limits in the Standard are complete and a peer review process has affirmed that the analyses are adequate.

2.5.1 Quality Assurance

The activities described in Section 2.7 will be performed in compliance with a detailed Quality Assurance Program. The goal of this program is to assure that research and performance assessment activities are controlled and well documented, using good laboratory, engineering, and management practices. Quality assurance is a tool to assist management in planning, executing, and documenting the experimental program. By supporting the experimental program and assuring accurate records, quality assurance will contribute to the defensibility of the experimental data and resulting conclusions.

The quality assurance (QA) requirements for the Performance Assessment Program are defined in a Quality Assurance Program that complies with the basic requirements and applicable supplements of ANSI/ASME NQA-1-1986 (QA Program Requirements for Nuclear Facilities), DOE Order 5700.6B, DOE AL Order 5700.6B (General Operations Quality Assurance), Chapter 11 (Quality Assurance) of the WIPP Final Safety Analysis Report, WIPP DOE 87-007 QA Operations Program, WIPP Project Office Management Directives, and the Sandia National Laboratories Quality Plan and Organization 6000 QA Policy. All activities associated with repository characterization as well as all performance assessment will comply with the requirements of the Quality Assurance Program.

2.6 Elements of the Performance Assessment Program

This section provides a description of the work elements and subelements that support completion of the Performance Assessment Program. The work is divided into five elements and corresponding subelements and information needs (Table 2-1). Each subelement provides a list and description of the information needs required to address that subelement. Each information need identified has been given a four-digit reference number. The first two digits refer to the element it supports, the third digit refers to the subelement, and the fourth digit refers to the specific information need established under the subelement. In addition, each information need description provides a reference (with page number) to the relevant activities that support the information need.

ELEMENT 1.1 Scenario Screening

The WIPP Project is in the process of publishing a report (Hunter, 1989) that will identify all processes and events examined for inclusion in the WIPP consequence analysis and justify dismissal of those processes or events that have been screened out and require no further consideration. These events and processes will be screened on the basis of probability, physical reasonableness, consequence, and regulatory interest. A second report, identifying the probabilisitic scenarios retained for the initial consequence analysis, will define the disposal system conceptual models, which must be simulated for the 10,000-year performance. It is expected that approximately 10 significant scenarios will be thoroughly analyzed; the remainder are not expected to contribute significantly to the complementary cumulative distribution function.

A number of scenarios, events, and processes require further consequence analyses to determine whether they are of regulatory interest. These analyses are part of the screening process and may be relatively simple or complex. Screening begins with analyses of the particular events or processes listed below. The subelements do not necessarily correspond to scenarios to be retained for the final consequence analysis. After examining Hunter's (1989) results, these subelements were chosen for early examination because: (1) they are likely to be dismissed as a result of the screening analyses; (2) they are ready for screening analysis; and (3) results of these analyses can be used to guide data collection, further screening efforts, and both preliminary and final consequence analyses. Other analyses may be subsequently defined; both would be documented in later supplements.

Performance Assessment Activities PA.1 and PA.2 address the information needs for Element 1.1.

Subelement 1.1.1 Climatic Change

This subelement requires screening of climatic change processes (that should be included in the final consequence analysis) to determine whether any reasonable change can cause variations in flow in any of the stratigraphic units of the controlled area within 10,000 years.

The information needs for this subelement include

1.1.1.1 Modern Hydrology: three-dimensional models of the hydrologic characteristics of the region and the controlled area.

1.1.1.2 Paleoclimatology/Hydrology: predictions of future climatic changes and their effects on the hydrology.

1.1.1.3 Recharge: incorporating potential recharge rates and changes in the hydrologic model.

Subelement 1.1.2 Nuclear Criticality

This subelement requires determining whether any likely conditions could lead to nuclear criticality in the disposal system after the shafts are sealed, and whether the response of the disposal system would significantly affect the results of the consequence analysis by increasing thermal loading or changing the radionuclide inventory.

The information needs for this subelement include

1.1.2.1 Radionuclide Inventory: inventory of radionuclides to be disposed of at the WIPP facility.

1.1.2.2 Radionuclide Distributions and Concentrations: a description of the distributions and concentrations of those radionuclides of concern throughout the waste panels over the regulatory time period.

1.1.2.3 Reconcentration: incorporating the potential for reconcentration of radionuclides outside the waste panels into the criticality calculations.

Subelement 1.1.3 Human Intrusion

Human-intrusion events that must be screened include boreholes into deeper geologic formations, the effects of two boreholes through one panel, and solution mining.

This subelement requires (1) determining whether drilling into deeper geologic formations is significant; (2) determining whether penetration of the same waste panel by two boreholes is likely to alter the flow pattern in the Culebra Dolomite Member within the controlled area; and (3) determining whether solution mining is probable, and if so, whether it is likely to affect releases.

The following information needs for this subelement will be obtained from field studies or from the literature:

1.1.3.1 Flow Direction in Deeper Geologic Formation Boreholes: the expected direction of flow in a borehole between the Culebra Dolomite Member and the deeper geologic formations.

1.1.3.2 Room Effects: the effect of the flow direction in deeper geologic formation boreholes on an intersected disposal room.

1.1.3.3 Deeper Geologic Formation Flow: the rate of flow to the accessible environment in the deeper geologic formation if flow is confirmed to be downward from the Culebra Dolomite Member.

1.1.3.4 Culebra Dolomite Hydrology: a model of ground-water flow in the Culebra Dolomite.

1.1.3.5 Two-Borehole Effects: incorporating flow down a borehole, through a waste panel, up a second borehole, and back into a water-bearing unit.

1.1.3.6 Subsidence Zone: hydrologic properties of the subsided zone above an abandoned, collapsed potash mine in the site vicinity.

1.1.3.7 Flow Variations: changes in adjacent flow patterns caused by any of the above events.

Subelement 1.1.4 Seal Performance

This subelement requires identification of the major effects of nonstandard seal performance to determine which effects cannot be screened out.

The information needs for this subelement include

1.1.4.1 Seal Performance: data on seal component performance.

1.1.4.2 Failure Modes: potential modes of seal failure.

Subelement 1.1.5 Probability Assignment

This subelement requires assignment of a probability of occurrence to each scenario that cannot otherwise be screened out.

Information needs for this subelement include

1.1.5.1 Scenarios: identifying scenarios that require probability assignments.

1.1.5.2 Expert Opinion: obtaining expert opinion on the probabilities of events and processes that make up each scenario.

1.1.5.3 Probabilities: calculating or assigning a probability for each scenario.

ELEMENT 1.2 <u>Repository/Shaft System: Behavior Characterization and Performance Modeling</u>

The repository/shaft system is one part of the two-part disposal system. Performance of the repository/shaft system must be adequately simulated over 1,000- and 10,000-year periods to determine whether radionuclides can migrate to the surrounding formations or to the surface above the shafts. If such movement is predicted, then transport through the other part of the disposal system, the controlled area, must be adequately simulated (Element 1.3). For scenarios that change the expected performance without human intrusion, performance of the entire repository/shaft system may be simulated using the appropriate conceptual models of the disposal system. For most human-intrusion scenarios, the performance of only parts of the repository/shaft system may be simulated.

The behavior of the integrated repository and shaft system, including the response of the waste disposal rooms (Subelement 1.2.1), panel seals (Subelement 1.2.2), drift backfill materials (Subelement 1.2.3), shaft seal systems (Subelement 1.2.4), and transport (Subelement 1.2.5) must be sufficiently understood to support a reasonable expectation of compliance with the Standard. Characterization requires theoretical analyses and model studies, laboratory testing, and in situ investigations.

The most likely natural mechanisms for transporting radionuclides out of the repository and into the surrounding rock are ground water movement and diffusion through ground water. Disposal systems can be designed to prevent or delay radionuclide migration into the accessible environment. Backfill barriers, specifically mixtures of bentonite clay and crushed salt, are being designed to provide a material that will eventually have permeabilities low enough to significantly limit movement of fluids. The backfill's sorptive properties and low permeability may slow the migration of radionuclides if dissolution of the waste occurs.

Gases generated by the bacteriological and radiological decomposition of the TRU waste and corrosion of the drums could become a driving force for radionuclide movement, if intermediate or final consolidation states of the waste disposal rooms include appreciable pressurized, gas-filled porosity. However, additives could consume or act as getters for most gases generated within the waste room and eliminate gas as a driving force for radionuclide migration.

The characteristics of the source term and predictions of how these characteristics change over time are also considerations for waste disposal. Knowledge of the initial waste characteristics and their subsequent alterations through radioactive decay and possible organic complexing is required to design adequate waste confinement systems. The effects of backfill materials and additives and of brine inflow must also be known. Estimates of the radionuclide and nonradionuclide inventories of the waste, including physical and chemical states, are necessary for evaluating the capability of a disposal room to confine radionuclides. These estimates are necessary for predicting the movement of radionuclides out of the repository toward the accessible environment.

Waste form confinement within a waste disposal room isolates radioactive material from the accessible environment. Isolation is achieved if the host rock (including any sealed manmade penetration within it and any disturbed rock adjacent to the panels and seals) forms a barrier to radionuclide transport. Waste isolation focuses on the integrity and continuity of rock salt, its potential for encapsulating the waste through creep closure of waste disposal rooms, its ability to deform without severe fracturing and fracture propagation, its ability to self-heal fractures from natural or manmade disturbances, and its inherent resistance to fluid flow (low permeability).

Penetrations made in characterizing the WIPP site and constructing the facility could provide pathways for radionuclide release. As a result, seals in underground openings and in shafts and plugs in boreholes are required for waste isolation. These barriers must perform effectively soon after emplacement as well as throughout the 10,000-year period of regulatory interest.

Performance of the repository and shaft system can be simulated for the final consequence analysis when

- The repository/shaft system's behavior has been defined and modeled, and testing has shown that the system is adequately understood.
- The understanding of the repository/shaft system's effect on long-term containment has been determined by models and analyses to be adequate for input to performance assessment.
- Computational models for performance assessment scenario simulations can be developed from and supported by more detailed mechanistic or phenomenological models and interpretations of the repository and shaft system.
- A peer review process has affirmed that the characterization has been completed to an acceptable confidence level.

Subelement 1.2.1 <u>Waste Disposal Room Behavior and Modeling</u>

Waste disposal room behavior must be characterized. The room behavior is affected by the interactions among (1) gas generated by corrosion or bacteriological and radiological decomposition of the emplaced TRU waste; (2) creep closure of the surrounding salt formation encapsulating the waste and backfill materials; (3) brine flow into and potentially out of the rooms; and (4) the potential for gas flow out of the repository, either through seal components (at early times) or the far-field host rock (at long times). The consequences of generated gas, fluid inflow and outflow through the disturbed rock zone, and the interactions of room deformation, backfill consolidation, waste container deformation and fluid absorption in the solid waste/backfill matrix must be understood, both with respect to radionuclide migration and with respect to hazardous components of the waste. This subelement will define the total system interaction that would, in any way, impact waste confinement, encapsulation, and movement of both radionuclides and hazardous waste components out of the room.

Performance assessment requires simulating the behavior of the waste disposal rooms both while the rooms are in a transient state and after a final steady state has been attained. It also requires simulating disturbance of the rooms by human intrusion in either state. Simulating room behavior will determine the quantities of radionuclides and brine that can be moved out of the rooms and through the panels and shafts, the surrounding rock in the disturbed rock zone, or through penetrating boreholes under various scenarios. Because waste will also be emplaced in the drifts that connect the panels, performance of these drifts south of the northernmost panel seals will be simulated using appropriate models.

Information needs for this subelement include

1.2.1.1 Source Term: (a) defining the room source term (considering the waste inventory, its radioactive composition, organic and inorganic chemical constituents, decomposition processes including radiolysis, microbial activity, corrosion, and radioelement speciation in solution), which considers the disposal room environment from the time of waste emplacement to final equilibration; and (b) developing mathematical models that consider variability in the source term resulting from variability in brine inflow, brine chemistry, gas volume and chemistry, and room consolidation in various scenarios. Evaluation of engineered modifications to waste and backfill are specifically included in this effort. Modeling capability will include those disturbed conditions under which large quantities of water or brine are introduced or injected (e.g., pressurized brine occurrence scenario) and the room contents are disrupted by drilling (including mechanical removal of wastes in drill cuttings and drilling mud, erosion and entrainment of room contents by water or brine, and leaching). The source term includes (1) the quantities of important radionuclides and hazardous materials in the WIPP inventory that might be mobilized for possible transport to the accessible environment; (2) the scenario-dependent rates at which these materials might be mobilized; and (3) examination of potential effects resulting from interaction of hazardous materials with waste, backfill, and seal components.

Relevant Activities:
- Lab: S.1.1.4 (p. 2-99), S.1.1.5 (p. 2-102)
- Modeling: S.1.2.6 (p. 2-109)
- In Situ: S.1.3.2 (p. 2-112), S.1.3.3 (p. 2-114)
- PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.2 Backfill: (a) understanding the behavior of a "design-basis" crushed salt and bentonite-clay backfill mixture(s) surrounding the TRU waste drums during reconsolidation; (b) understanding the backfill's capacity for consuming brine, gas, radionuclides, and VOCs if additives (getters) are mixed into the backfill; (c) evaluating the potential impact of any proposed engineering modifications to backfill other than those (e.g., getters) presently being considered; and (d) incorporating mechanical, hydrologic, and geochemical properties and effects of backfill on the radionuclide source term, gas generation, reconsolidation, resaturation, and retardation in appropriate mathematical models and data sets.

Relevant Activities:

Lab:	S.1.1.1 (p. 2-96), S.1.1.2 (p. 2-97), S.4.1.2 (p. 2-169), S.4.1.3 (p. 2-170)
Modeling:	S.1.2.1 (p. 2-104), S.1.2.3 (p. 2-106)
In Situ:	S.1.3.1 (p. 2-111), S.3.3.12 (p. 2-161)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.3 Container Response: (a) determining the time-dependent reduction in void volume that would take place in each container when disposal room closure reconsolidates the backfill, ruptures the container, collapses the container and compacts its contents into a solid matrix; (b) defining the intermediate and final states of the container, backfill, and fluid system; (c) determining the effects of proposed modifications of the waste form; and (d) incorporating the effects of reconsolidation, resaturation, and gas generation in appropriate mathematical models and data sets on waste containers.

Relevant Activities:

Lab:	S.1.1.3 (p. 2-98), S.3.1.1 (p. 2-136), S.3.1.2 (p. 2-137), S.3.1.4 (p. 2-140)
Modeling:	S.1.2.2 (p. 2-105), S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143)
In Situ:	S.1.3.1 (p. 2-111), S.3.3.12 (p. 2-161)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.4 Closure: (a) determining the time-dependent rates at which the disposal room closes, based on the mechanisms deforming the surrounding salt and stratigraphic marker beds (where appropriate) (deformation results when salt is subjected to overburden stresses and room- and panel-geometry effects; this behavior is affected by clay seams and anhydrite layers, which result in fractures and near-field dilation, followed by partial healing due to redistribution of compressive stresses); and (b) developing mathematical models of room closure that account for time dependent room and panel geometry, creep, structural support of the backfill, drum collapse, internal gas generation, and (to the extent possible) the mechanical behavior of the disturbed rock zone around the facility.

Relevant Activities:

Lab:	S.3.1.1 (p. 2-136), S.3.1.2 (p. 2-137), S.3.1.3 (p. 2-139), S.3.1.4 (p. 2-140)
Modeling:	S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.3 (p. 2-144), S.3.2.6 (p. 2-149)
In Situ:	S.3.3.12 (p. 2-161)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.5 Brine Inflow and Room Resaturation: (a) determining the time-dependent rates of brine inflow from the formation into the disposal room, as influenced by the pattern and density of rock fractures or other continuous flow paths, by stress differentials around the excavated disposal room opening, by the presence of MB139 and other stratigraphic discontinuities, and by the rate of internal gas pressurization; (b) determining the fluid-flow properties of halite and other rock types in both the far-field and near-field domains; and (c) developing mathematical models of room resaturation that account for variability in brine-inflow rates, unsaturated and two-phase flow, gas-generation effects, effects of the disturbed rock zone, and the time-dependent response of both waste and backfill to fluid flow.

Relevant Activities:

Lab:	S.3.1.5 (p. 2-141)
Modeling:	S.3.2.4 (p. 2-146), S.3.2.6 (p. 2-149)
In Situ:	S.3.3.4 (p. 2-153), S.3.3.6 (p. 2-155), S.3.3.7 (p. 2-156), S.3.3.8 (p. 2-157), S.3.3.9 (p. 2-158), S.3.3.13 (p. 2-162)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.6 Gas Generation and Behavior: (a) experimentally determining the gas compositions, net generation rates, and relative importance of mechanisms involving radiolysis, microbial activity, and corrosion for as-received waste, modified waste, and both present and modified backfill; (b) determining the behavior of VOCs, including possible effects on backfill behavior and materials compatibility; and (c) developing mathematical models that include rates of gas production and removal, potential pressure buildup, and the effects of this buildup on waste compaction, room closure, brine inflow, and gas generation and potential release resulting from in situ waste and container decomposition.

Relevant Activities:

Lab:	S.1.1.2 (p. 2-97), S.1.1.4 (p. 2-99), S.1.1.5 (p. 2-102)
Modeling:	S.1.2.6 (p. 2-109)
In Situ:	S.1.3.2 (p. 2-112), S.1.3.3 (p. 2-114)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.7 Disturbed Rock Zone: (a) defining and characterizing the disturbed rock zone that excavation produces in the host rock surrounding the disposal room (including both halite and other rock types); and (b) investigating the time-dependent behavior of the disturbed rock zone and its effect on permeability, fluid flow, radionuclide transport capacity, gas transport, gas-storage capacity, and flow into and out of the storage rooms.

Relevant Activities:

Lab:	S.3.1.3 (p. 2-139), S.3.1.5 (p. 2-141)
Modeling:	S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.5 (p. 2-147), S.3.2.6 (p. 2-149)

In Situ: S.3.3.9 (p. 2-158), S.3.3.12 (p. 2-161)
PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.8 Systems Interactions: (a) understanding the synergistic behavior of the above components as they affect the total performance of the waste rooms and panels, including effects of room closure, backfill, wastes, brine, and gas; (b) incorporating these effects in appropriate mathematical models.

Relevant Activities:
Lab: S.1.1.3 (p. 2-98)
Modeling: S.1.2.1 (p. 2-104), S.1.2.2 (p. 2-105), S.1.2.4 (p. 2-107)
In Situ: S.1.3.1 (p. 2-111)
PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.1.9 Disposal Room Design: modifying or refining the existing room design, based on information acquired during the WIPP Test Phase, if necessary. Systems analysis of engineered modifications to waste forms, backfill, and emplacement approaches will be performed in parallel with the current testing program; these analyses will consider the long-term isolation characteristics of materials placed in the room.

Relevant Activities:
Lab: S.1.1.1 (p. 2-96), S.3.1.1 (p. 2-136), S.3.1.2 (p. 2-137), S.3.1.3 (p. 2-139), S.3.1.4 (p. 2-140), S.3.1.5 (p. 2-141)
Modeling: S.1.2.2 (p. 2-105), S.1.2.4 (p. 2-107), S.1.2.5 (p. 2-108), S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.3 (p. 2-144)
In Situ: S.1.3.2 (p. 2-112)
PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Disposal Room Data Base

Investigations concerning disposal room behavior provided the following extensive data base and understanding of phenomena that can be applied to an assessment of waste confinement and isolation:

- The overall understanding of expected disposal-room behavior, including uncertainties, was developed and documented by Lappin et al. (1989a). The conceptual model was used in deterministic calculations of expected WIPP behavior to 10,000 years.

- Waste container buoyancy, temperature increase at water-bearing strata and ground surface, deformation at water-bearing strata and ground surface, and surface subsidence all have been found insignificant for conditions at WIPP.

- Sophisticated constitutive models have been formulated from laboratory tests of rock specimens, accounting for all major observed mechanical behaviors and thermal conductivity observed in the laboratory. However, these models at present do not adequately describe the observed behavior of the Disturbed Rock Zone (DRZ).

- Numerical codes have been developed that can solve large-scale, two-dimensional problems with multiple layers of nonlinear materials. Three-dimensional codes having significant potential are being developed.

- Benchmarking and parallel calculation exercises have provided confidence in the precision of the codes available for structural calculations.

- Reference constitutive laws and material parameters have been established so that calculations may proceed for the waste room/panel configuration.

- A series of large-scale, in situ tests has been fielded and is providing high quality data on structural interactions, fluid flow, and waste container performance. Analyses of the in situ results are proceeding.

- Performance of CH- and RH-TRU waste containers in the WIPP environment has been examined through accelerated test data and found to be predictable.

- Structural response of CH-TRU waste containers has been determined for early time loadings.

- The reconsolidation and sorptive properties of crushed salt/clay-backfill mixtures are generally understood. Additives to enhance waste confinement in the disposal room are being investigated.

- Early laboratory, modeling, and in situ investigations of brine flow in the host rock and into disposal rooms have been completed and evaluated.

- Data on the disturbed rock zone surrounding an excavated opening underground have been acquired and the disturbed rock zone's influence on waste confinement is being evaluated.

- Preliminary estimates of gas-generation rates and compositions due to microbial activity and anoxic corrosion were documented in Lappin et al. (1989a), in addition to the estimated range in actinide solubilities.

- A properly tailored backfill mixture has the potential to absorb at least as much brine as the maximum calculated inflow.

Subelement 1.2.2 Panel Seal Behavior and Modeling

The panel sealing system's capability to function for the required period as an internal repository barrier for radionuclide migration to the access drifts must be understood. This includes external effects that influence the sealing system behavior and the behavior's performance under changing physical, chemical, and environmental conditions. Seal behavior will be resolved when a sealing system has been developed, evaluated, and tested in situ, and found to perform as predicted.

Performance assessment requires simulating transport through or around the panel seals during the transient state and after a steady reconsolidation state has been attained; it also requires simulating panel seal disturbance in either state. The computational model will include flow through the seals, between the host rock and the seal, and through the surrounding disturbed rock zone. Simulating panel seal behavior will determine the quantities of waste, brine, and gas that can be moved through or around the panel seals in various scenarios.

Information needs for this subelement include

1.2.2.1 Disturbed Rock Zone and Fluid-Flow Characteristics: (a) determining the permeability and fluid-flow properties of the surrounding rock units so that the rate of brine influx to disposal rooms and potential gas buildup and dissipation out of disposal rooms to the panel seals can be understood; (b) examining other fluid flow influences such as excavation effects, existing natural anomalies, and pore pressure phenomena that may affect sealing system performance; and (c) developing a mathematical model of transport through the disturbed rock zone, accounting for changes in the behavior of the disturbed rock zone around the panel seals, and for resaturation and retardation.

Relevant Activities:

Lab:	S.1.1.1 (p. 2-96), S.2.1.2 (p. 2-121), S.3.1.5 (p. 2-141)
Modeling:	S.1.2.1 (p. 2-104), S.2.2.1 (p. 2-123), S.3.2.4 (p. 2-146), S.3.2.5 (p. 2-147), S.3.2.6 (p. 2-149)
In Situ:	S.3.3.4 (p. 2-153), S.3.3.5 (p. 2-154), S.3.3.9 (p. 2-158)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.2.2 Sealing System: (a) understanding the behavior of seal materials under in situ conditions over the long term; (b) evaluating structural stability and chemical compatibility flow restriction capability, and emplacement requirements; (c) understanding the synergistic effects and performance of the entire panel sealing system and the host rock, particularly the capability of the seal to restrict fluid-flow and radionuclide transport from the panel; (d) understanding the integrated, long-term interactions between seal system components, the host rock and the expected waste matrix (including fluids, backfill, and the hazardous waste components and radionuclide source term materials); and (e) developing a mathematical model of transport through and around the seals, accounting for retardation and for possible disintegration and/or fracture of the seals.

Relevant Activities:

Lab:	S.2.1.1 (p. 2-120), S.2.1.2 (p. 2-121), S.2.1.3 (p. 2-122)
Modeling:	S.2.2.1 (p. 2-123), S.2.2.2 (p. 2-124)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.2 (p. 2-128)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.2.3 Closure: (a) understanding the time-dependent behavior of the interface between the seal and host rock units and the effects that rock creep closure has on the structural integrity of the sealing system, including healing of the disturbed rock zone surrounding the panel entry; (b) evaluating the mechanisms required for restricting fluid flow and resisting displacement at the interface and the reactivity of the seal with the rock units, considering the influence of the disturbed rock zone; and (c) developing a mathematical model of panel closure, accounting for panel drift and seal geometry, creep, and structural interaction of the seals from emplacement to final structural equilibration.

Relevant Activities:

Lab:	S.2.1.3 (p. 2-122), S.3.1.1 (p. 2-136), S.3.1.2 (p. 2-137), S.3.1.3 (p. 2-139), S.3.1.4 (p. 2-140)
Modeling:	S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.3 (p. 2-144), S.3.2.6 (p. 2-149)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.2 (p. 2-128)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.2.4 Sealing Criteria, Concepts, and Designs: (a) defining a panel sealing system that will be effective as a barrier under the EPA Standard; (b) establishing quantitative parameters for the sealing system for use in performance assessment; (c) establishing engineering criteria and concepts for more detailed panel seal designs.

Relevant Activities:

Lab:	S.2.1.1 (p. 2-120), S.2.1.2 (p. 2-121), S.2.1.3 (p. 2-122)
Modeling:	S.2.2.2 (p. 2-124), S.3.2.6 (p. 2-149)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.2 (p. 2-128), S.3.3.4 (p. 2-153), S.3.3.5 (p. 2-154)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Panel Seal Data Base

The long-term strategy for sealing panels includes use of reconsolidated, crushed salt at the panel entryways. This reconsolidated salt will eventually form a seal that approaches the density, permeability, strength, and other mechanical properties of the intact salt.

The present data base for panel seal behavior is summarized below (Stormont, 1988a; Tyler et al., 1988):

- A reference panel sealing concept appears adequate to ensure long-term waste isolation. Decisions on usable approaches to sealing in the marker beds have yet to be made.

- The principal long-term sealing strategy involves reconsolidation of crushed salt. Studies regarding crushed salt behavior have resulted in a numerically implemented, constitutive equation for salt reconsolidation, and emplacement techniques have been verified by in situ tests.

- Laboratory and in situ data indicate that bentonite-based seals will be viable until the crushed salt component of the seal has completely reconsolidated.

- Reference cementitious mixtures have been developed and emplaced in situ. A structural model for the cementitious seal/rock system based on the in situ data will be further evaluated.

- Characterization of the disturbed rock zone, principally by gas flow tests, has guided panel seal concepts.

- A series of intermediate-scale, in situ sealing tests has yielded high quality thermal, structural, and fluid-flow data for candidate sealing materials in various configurations. Data and preliminary analysis reports have been completed and others will be prepared.

- Initial analyses of sealing systems, incorporating structural and fluid-flow response of the sealing material and the host rock, suggest the current seal system design should be successful.

- The current brine inflow model, based on Darcy-like flow, satisfactorily agrees with all available brine inflow data for unheated and heated WIPP boreholes and with independent in situ measurements of near-field gas and brine flow in the WIPP host rock. Scaled-up predictions and certain mechanistic assumptions in the model concerning brine pore pressure and flow paths will be tested with data from ongoing and planned WIPP in situ tests.

Subelement 1.2.3 <u>Access Drift Behavior and Modeling</u>

The performance of backfill materials in the access drifts must be understood (i.e., the potential for fluid flow and resulting radionuclide transport between the waste disposal panel and shaft seals). The reconsolidation behavior of the backfill under overburden stresses due to creep closure and under environmental effects, particularly brine inflow, will be investigated.

Performance assessment requires simulating transport through or around the access drifts between the panel seals adjacent to the disposal area and the seals at the bases of the four shafts during the transient state and after reconsolidation has reached a steady state. The computational model will include flow through the drift backfill, between the host rock and the backfill, and through the surrounding disturbed rock zone. Because these access drifts must remain open for the entire operational phase of WIPP, the history of the disturbed rock zone and its response to remedial actions to maintain the access drifts is likely to be complex. Simulating drift behavior will determine the quantities of radionuclides and brine that can be moved through or around the drift in various scenarios.

Information needs for this subelement include

1.2.3.1 Backfill: (a) defining the extent of crushed salt reconsolidation (and possible additives) as a function of the rate of drift closure; (b) understanding brine inflow to the excavations; and (c) evaluating fluid-flow characteristics of reconsolidated backfill; and incorporating backfill properties and the effects of reconsolidation, resaturation, and retardation in appropriate mathematical models and data sets.

Relevant Activities:
- Lab: S.1.1.1 (p. 2-96), S.2.1.2 (p. 2-121)
- Modeling: S.1.2.1 (p. 2-104), S.1.2.3 (p. 2-106), S.2.2.1 (p. 2-123)
- In Situ: S.1.3.1 (p. 2-111)
- PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.3.2 Disturbed Rock Zone: developing a mathematical model of structural response and flow and transport through the disturbed rock zone, accounting for both resaturation and retardation.

Relevant Activities:
- Lab: S.3.1.3 (p. 2-139), S.3.1.5 (p. 2-141)
- Modeling: S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.5 (p. 2-147), S.3.2.6 (p. 2-149)
- In Situ: S.3.3.9 (p. 2-158), S.3.3.12 (p. 2-161)
- PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.3.3 Closure: (a) determining the rate at which the drift closes and the surrounding rock deforms during salt creep subjected to overburden stress and excavation geometry effects (drift response in some locations could result in superficial fracturing followed by healing due to redistribution of compressive stresses); and (b) developing a mathematical model of drift closure that accounts for geometry of the drifts, creep, disturbed rock zone formation, and structural interaction of the backfill.

Relevant Activities:
- Lab: S.3.1.1 (p. 2-136), S.3.1.2 (p. 2-137), S.3.1.3 (p. 2-139), S.3.1.4 (p. 2-140)
- Modeling: S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.3 (p. 2-144)
- In Situ: None
- PA: PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Access Drift Data Base

Extensive investigations of materials appropriate for backfilling excavations following waste emplacement have been completed (Tyler et al., 1988). These studies concerned sealing (Stormont, 1988a) and disposal room backfill and structures (Nowak, 1980; Nowak, 1981; Pfeifle, 1987; Tyler et al., 1988). The results are directly applicable to backfill material emplacement in drifts during repository sealing. In summary, the investigations for behavior of emplaced backfill and for the structural response of the drift configurations have provided the following data:

- Reference constitutive models and computer codes including multi-layer and nonlinear material properties have been developed to solve two-dimensional, structural problems.

- Recent structural calculations, which used the Tresca flow rule and a simplified constitutive model, provided good agreement with in situ data (within 2 percent for vertical closures and 18 percent for horizontal closures).

- In situ tests have provided high quality data on structural interaction and fluid flow that are applicable to preliminary analyses of interactions between the drift and the backfill and of the response of backfill materials.

- Reconsolidation and sorptive properties of candidate backfill materials, particularly crushed salt and clay mixtures, are generally understood. Effectiveness of backfill additives in retarding radionuclide transport is being investigated.

Subelement 1.2.4 Shaft Seal Behavior and Modeling

The shaft sealing system must function as a barrier to migration of radionuclides up to the water-bearing strata in the Rustler Formation and to the flow of fluids down to the facility horizon for the required period. External influences on sealing system behavior include changing structural conditions (stress and creep) and chemical environments in the different geologic units of WIPP stratigraphy within which shaft seals will be placed. Characterization requires development, evaluation, and testing of shaft seal systems that perform their intended purpose and are sufficiently understood to permit long-term performance predictions.

Performance assessment requires simulating transport through or around the shafts and seals from the repository horizon to the scenario-dependent discharge horizon. This requires the ability to simulate the entire length of the shafts to the surface after a steady reconsolidation state has been attained and perhaps during the transient state, as well as under various conditions of possible seal failure. The computational model must include leakage down the shaft from overlying water-bearing units and transport up the shaft as required by various scenarios. Flow must be simulated through the shaft seals and backfill, through the surrounding disturbed rock zone, and between the host rock and the shaft components. Shaft behavior simulations will determine the quantities of unsaturated brines from overlying water-bearing units that might enter the repository through the shafts and will also determine the quantities of radionuclides and brine that can be moved through or around the shafts in various scenarios.

Information needs for this subelement include

1.2.4.1 Backfill: (a) incorporating shaft backfill properties and the effects of reconsolidation, resaturation, and retardation, and the effects on the backfill of dissolution/precipitation from downward leakage of overlying units in appropriate mathematical models and data sets.

Relevant Activities:

Lab:	S.1.1.1 (p. 2-96), S.2.1.2 (p. 2-121)
Modeling:	S.1.2.1 (p. 2-104), S.1.2.3 (p. 2-106), S.2.2.1 (p. 2-123)
In Situ:	None
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.4.2 Sealing System: (a) understanding the long-term behavior of sealing materials subjected to in situ configuration and geometry effects; (b) understanding brine inflow to the excavations; (c) evaluating structural and chemical stability of seal materials emplaced in the stratigraphic units, flow restriction capability, and emplacement techniques; (d) evaluating the impact of the coupled interactions of brine inflow, closure, and crushed-salt reconsolidation process; (e) evaluating the ability of the entire shaft-seal system and the host rock to restrict fluid flow to the repository from the overlying water-bearing strata and from the repository up the shaft to the overlying strata and surface, considering the long-term physical and chemical stability of each sealing system component emplaced in the various stratigraphic units in the shaft; and (f) developing a mathematical model of flow and transport through and around the seals, accounting for retardation and for possible disintegration and/or fracture of the seals, with accompanying dissolution/precipitation from downward leakage.

Relevant Activities:

Lab:	S.2.1.1 (p. 2-120), S.2.1.2 (p. 2-121), S.2.1.3 (p. 2-122)
Modeling:	S.2.2.1 (p. 2-123), S.2.2.2 (p. 2-124)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.2 (p. 2-128)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.4.3 Disturbed Rock Zone and Fluid-Flow Characteristics: (a) determining the permeability, hydrologic behavior, and brine inflow properties of WIPP shaft stratigraphic units so that seal system effectiveness and host rock influence at various levels can be understood, considering effects of the disturbed rock zone on fluid-flow properties of the host rock over time; and (b) developing a mathematical model of flow and transport through the disturbed rock zone accounting for resaturation, retardation, and changes in brine chemistry.

Relevant Activities:

Lab:	S.1.1.1 (p. 2-96), S.2.1.2 (p. 2-121), S.3.1.5 (p. 2-141)
Modeling:	S.1.2.1 (p. 2-104), S.2.2.1 (p. 2-123), S.3.2.4 (p. 2-146), S.3.2.5 (p. 2-147), S.3.2.6 (p. 2-149)
In Situ:	S.3.3.6 (p. 2-155), S.3.3.7 (p. 2-156), S.3.3.8 (p. 2-157), S.3.3.10 (p. 2-159), S.3.3.11 (p. 2-160), S.4.3.2 (p. 2-180)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.4.4 Closure: (a) understanding the interfaces between shaft seals and host rock and the effects that shaft closure rates and mechanisms have on the reconsolidation of compacted crushed salt used in seals and on other seal materials, considering the mechanisms required for ensuring fluid-flow restriction and displacement resistance at the interface, the reactivity of the seal components with the host rock, and the influence of the disturbed rock zone; and (b) developing a mathematical model of shaft closure that accounts for geometry, creep, and structural interaction of the seals with the surrounding rock.

Relevant Activities:

Lab:	S.3.1.1 (p. 2-136), S.3.1.2 (p. 2-137), S.3.1.3 (p. 2-139), S.3.1.4 (p. 2-140)
Modeling:	S.2.2.2 (p. 2-124), S.3.2.1 (p. 2-142), S.3.2.2 (p. 2-143), S.3.2.3 (p. 2-144), S.3.2.6 (p. 2-149)
In Situ:	S.2.3.1 (p. 2-125), S.3.3.1 (p. 2-150), S.3.3.2 (p. 2-151)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.2.4.5 Sealing Criteria, Concepts, and Designs: (a) determining shaft sealing requirements for an effective engineered barrier under the EPA Standard by establishing quantitative sealing system parameters at specific depths in the shaft so that performance assessment studies, criteria, concepts, and engineering designs for shaft seals can be completed.

Relevant Activities:

Lab:	None
Modeling:	S.2.2.2 (p. 2-124)
In Situ:	S.2.3.2 (p. 2-128), S.3.3.1 (p. 2-150), S.3.3.2 (p. 2-151), S.3.3.3 (p. 2-152), S.3.3.10 (p. 2-159)
PA:	PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Shaft Seal Data Base

The data base for evaluating sealing materials and seal designs has been derived from laboratory and in situ testing, as well as from numerical modeling and analysis. The laboratory work has focused on sealing materials: crushed salt blocks and quarried salt, cementitious materials, and clays (primarily bentonite). For salt, laboratory and in situ studies have been directed toward understanding reconsolidation of crushed salt and the resulting fluid-flow properties. For bentonite, the density, swelling, and fluid-flow properties have been investigated. The long-term stability and integrity of salt and bentonite, as well as cement and cement/bentonite mixtures, have been the primary focus of laboratory investigations (Tyler et al., 1988).

In summary, the present data base (Tyler et al., 1988; Stormont, 1988a) for behavior of shaft seals suggests the following:

- Reference concepts for shaft seals appear adequate to ensure long-term waste isolation, subject to further evaluation.
- The principal long-term sealing strategy depends on reconsolidation of crushed salt at the lower level of the shaft. Studies of crushed salt behavior have resulted in a numerically implemented constitutive equation for salt reconsolidation. Emplacement techniques have been proven by in situ tests.
- Laboratory and in situ test data indicate that bentonite-based seals will effectively restrict fluid flow over the short term.
- Reference cementitious mixtures have been tested in situ. A structural model for the cementitious seal/rock system based on in situ data will be further evaluated.
- Characterization of the disturbed rock zone, principally by brine and gas flow tests, has guided shaft sealing concepts.
- A series of intermediate-scale, in situ sealing tests has provided high quality thermal, structural, and fluid-flow data for candidate sealing materials in various configurations. Data and preliminary-analysis reports have been completed.
- Initial analyses of sealing systems, incorporating structural and fluid flow response of the sealing material and host rock, have been completed. Calculations of creep closure have been used to evaluate the reconsolidation of crushed salt.

Subelement 1.2.5 Transport Modeling

Appropriate computational models will be selected, adapted, and optimized for coupling with the hydrologic-flow computational models to model long-term transport of radionuclides through or around the repository/shaft system.

This subelement is addressed by performance assessment activity PA.5. Information needs for this subelement include

1.2.5.1 Subdomains: identifying important subdomains for transport modeling (e.g., including Marker Bed 139 as a transport path).

1.2.5.2 Transport Mechanisms: identifying important transport mechanisms for the various scenarios.

1.2.5.3 Transients: determining whether transport models capable of simulating transient hydraulic conditions, including specialized modeling components such as a brine-pocket model, are needed based on the results of scenario screening.

1.2.5.4 Transport Codes: selecting computational codes for transport in the repository/shaft system.

1.2.5.5 Optimization: optimizing coupling between hydrologic and transport domains and optimizing transport computational efficiency.

ELEMENT 1.3 Controlled Area: Behavior Characterization and Performance Modeling

The controlled area is the second part of the two-part disposal system. Modeling ground-water flow in the accessible environment and through the controlled area will establish boundary conditions for modeling transport out of the controlled area. Modeling ground-water flow in the controlled area will establish boundary conditions for the repository/shaft system. After the repository/shaft system model determines the source term, modeling of transport in the controlled area will determine the release to the accessible environment.

For undisturbed performance (expected conditions), the performance of the controlled area must be simulated to determine whether migration of radionuclides to the accessible environment can occur, if the repository/shaft system model predicts migration into the controlled area. For scenarios which change the predicted behavior without human intrusion, the controlled area will be simulated again using the appropriate conceptual models of the disposal system. For some human-intrusion scenarios, the performance of some hydrologic units of the controlled area will be simulated.

Subelement 1.3.1 Los Medanos Regional Flow Modeling

The boundary conditions and flow and transport properties within geologic units of interest in the accessible environment must be defined well enough to reliably model conditions and radionuclide releases at the outer boundary of the controlled area over a 10,000-year time frame under undisturbed conditions and to model changes in flow and transport for disturbed conditions. The existing conceptual models and data bases characterizing the hydrologic flow must be extended to a three-dimensional computational model that will adequately simulate undisturbed and disturbed, long-term flow over a sufficiently large area to minimize boundary condition effects on flow in the controlled area.

The recent completion and comparison of isotopic, geochemical, and hydrologic studies (see Siegel et al., 1988) indicate that the hydrologic and geochemical setting of the Rustler Formation and shallower units at the WIPP site has changed significantly over approximately 10,000 years, the time frame of regulatory interest. Both flow direction within the Rustler Formation and the state of saturation within the Dewey Lake Red Beds appear to have changed during this time in response to the cessation of surficial recharge at and near the WIPP site at least 10,000 years ago.

Figure 2-1 shows the relationship of the regional Los Medanos model domain to the local domain; the controlled area lies within the local domain. The model domain for the Los Medanos model will include about eight stratigraphic layers. The lateral boundaries will be determined by sensitivity studies. The layers in the present model are, from the surface downward, the Dockum Group, the Dewey Lake Red Beds, five members of the Rustler Formation (Forty-niner, Magenta, Tamarisk, Culebra, and unnamed), and the Salado Formation This model domain extends laterally to natural boundaries, or far enough out to avoid boundary-condition effects on the simulation of flow in the controlled area.

The Los Medanos three-dimensional model will be completed and used to develop initial computational fields and to establish computational meshes for analyses of the scenarios retained for the consequence analysis.

Information needs for this subelement include

1.3.1.1 Culebra-Magenta: incorporating the Culebra-Magenta hydrologic connection into the Los Medanos model.

Relevant Activities:
- Lab: None
- Modeling: None
- In Situ: None
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.1.2 Dewey Lake Red Beds: incorporating Dewey Lake Red Bed hydrologic parameters into the Los Medanos Model.

Relevant Activities:
- Lab: None
- Modeling: None
- In Situ: None
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.1.3 Culebra: incorporating fracture flow within the Culebra Dolomite into the Los Medanos Model, if transport calculations show that this phenomenon is important.

Relevant Activities:
- Lab: None
- Modeling: None
- In Situ: None
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.1.4 Fluid Density: incorporating updated fluid density data in the area south of the controlled area into the Los Medanos Model.

Relevant Activities:
- Lab: None
- Modeling: None
- In Situ: None
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85), PA.11 (p. 2-89)

1.3.1.5 Regional Boundary Conditions: incorporating additional hydrologic data for Clayton Basin, eastern boundary of the Los Medanos model, and southwest boundary of the model at Balmorrhea-Loving Trough into the Los Medanos model, if initial 10,000-year simulation shows that boundary conditions affect the results.

Relevant Activities:

Lab:	None
Modeling:	None
In Situ:	None
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.1.6 Recharge: (a) estimating temperature and precipitation in southeastern New Mexico over approximately the last 10,000 years (paleoclimate); estimating the effects of variations in temperature and precipitation on surficial recharge at and near the WIPP site and on the hydrologic settings and behavior of the Rustler Formation and Dewey Lake Red Beds over the last 10,000 years; (b) determining whether reasonably estimated changes in climate and hydrologic setting can have significant impact on groundwater travel times and transport behavior; and (c) incorporating potential recharge rates and changes in the Los Medanos model.

Relevant Activities:

Lab:	S.4.1.4 (p. 2-171)
Modeling:	S.4.2.1 (p. 2-173), S.4.2.3 (p. 2-177)
In Situ:	S.4.3.9 (p. 2-187), S.4.3.10 (p. 2-188), S.4.3.11 (p. 2-189)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.1.7 Extent of Dissolution: (a) estimating the possible extent of evaporite dissolution within the Rustler Formation over the next 10,000 years, and the possible effects of this dissolution on flow directions and rates within the Rustler; and (b) incorporating potential changes in the Los Medanos model.

Relevant Activities:

Lab:	None
Modeling:	S.4.2.3 (p. 2-177)
In Situ:	S.4.3.9 (p. 2-187), S.4.3.10 (p. 2-188), S.4.3.11 (p. 2-189)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Boundary Condition Data Base

Investigations applicable to establishing boundary conditions have provided the following data:

- Recent isotopic and geochemical studies are inconsistent with the assumption of steady-state boundary conditions, and the hydrology and geochemistry of the Rustler Formation appear to be still in transient response to a cessation of recharge occurring 12,000 to 16,000 years ago.

- Limited uranium-disequilibrium studies indicate that ground-water flow directions within the two Rustler dolomite water-bearing units have changed since the end of the last recharge episode.

- The isotopic character of the Rustler Formation is distinct from that of modern meteoric precipitation in the area.

- The limited radiocarbon data base supports the interpretation of no modern vertical recharge to the Culebra.

- Analyses from the Dewey Lake Red Beds indicate that some of the water in this unit may be "modern."

- In general, the stable isotope data base for the Rustler Formation is probably adequate.

- Two tests show that the Dewey Lake Red Beds are so impermeable that neither the state of saturation nor the permeability can be determined.

- There appears to be limited vertical fluid flow from the Rustler upward into the Dewey Lake Red Beds.

- A major involvement of surficial materials is indicated in crystallization of secondary gypsum veins within the Dewey Lake Red Beds. Secondary gypsum veins within the Rustler could not have crystallized in equilibrium with modern meteoric recharge in the area.

Subelement 1.3.2 Controlled Area Flow Modeling

The Salado Formation contains the underground workings of the WIPP facility, except for the four WIPP shafts, which penetrate overlying formations and the Salado Formation. Many of the subelements concerning the repository/shaft system, outlined in Element 1.2, include both the disturbed rock zone around the WIPP facility and the interaction of emplaced waste, backfill, and seals with the disturbed rock zone. However, the mechanical and hydrological behavior of the repository/shaft system is strongly influenced by the behavior of the geologic systems outside the disturbed rock zone.

The initial performance assessment site characterization results for non-Salado units will be used to assemble the Los Medanos three-dimensional model and the composite model of the controlled area to determine flow conditions for undisturbed performance. This approach assumes that the modern hydrologic settings and properties in the surrounding geology are not disturbed, except by the emplacement of shafts through the Rustler and overlying units. However, the undisturbed scenario requires evaluation of flow up and down the WIPP shafts and of transport up the shafts and through the Rustler Formation and Dewey Lake Red Beds to the accessible environment.

One human-intrusion scenario for the WIPP facility involves an incompletely plugged borehole interconnecting the Rustler/Dewey Lake Red Beds, the WIPP facility, and a brine occurrence within the Castile Formation. Brine occurrences are brines pressurized to near-lithostatic pressure and localized within fractured portions of the uppermost Castile Formation anhydrites. The high pressures associated with these brine occurrences have the potential to hydrofracture competent, unfractured rocks when in communication with the above geologic units, or to expand and extend preexisting fractures. Conventional practice in drilling, following penetration of a pressurized Castile brine occurrence, would include plugging, casing, and/or grouting, but the long-term effectiveness of these procedures remains to be demonstrated. Therefore, an understanding of the important flow and transport mechanisms within the Rustler and Dewey Lake Red Beds between an incompletely plugged hole and the accessible environment must be evaluated.

A second human-intrusion scenario involves borehole interconnection of the Bell Canyon Formation (underlying the Castile Formation), the WIPP facility, and the Rustler Formation; in this scenario, Castile brines are not included. In the WIPP Final Environmental Impact Statement (DOE, 1980) it was assumed that the result of such interconnection would be flow and transport upward into the Rustler Formation. More recent studies (Beauheim et al., 1983; Beauheim, 1986) indicate that fluid flow and transport resulting from interconnection of the Bell Canyon would be downward into the Bell Canyon.

The model domain for controlled area modeling will be 15 mi by 15.5 mi (24 km by 25 km). It will extend laterally beyond the boundary of the controlled area so that flow across the boundary into the accessible environment can be simulated without artificial boundary condition effects. The vertical domain may include the same layers as the Los Medanos model.

Information needs for this subelement include

1.3.2.1 Salado Formation: (a) determining and documenting permeabilities, long-term fluid pressures, brine contents, and degree of hydraulic saturation in Salado Formation halites, anhydrites, and clays in the far field; (b) determining whether the Salado Formation behaves as a continuous hydrologic system in the far field on the time scales of regulatory interest; (c) determining far-field deformation rates and mechanisms within the Salado Formation, and the mechanical interaction in the far field between the Salado and overlying units; and (d) developing a mathematical model of Salado Formation zone of influence around the repository and shafts.

Relevant Activities:

Lab:	None
Modeling:	S.3.2.2 (p. 2-143), S.3.2.3 (p. 2-144), S.3.2.4 (p. 2-146), S.3.2.5 (p. 2-147), S.3.2.6 (p. 2-149)
In Situ:	S.3.3.6 (p. 2-155), S.3.3.7 (p. 2-156), S.3.3.11 (p. 2-160), S.3.3.9 (p. 2-158), S.3.3.10 (p. 2-159), S.3.3.11 (p. 2-160), S.3.3.12 (p. 2-161), S.3.3.13 (p. 2-162)
PA:	PA.3 (p. 2-73), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.2 Culebra Dolomite Member: (a) determining the final, regional distribution of heads, transmissivities, and storativities in the Culebra Dolomite Member, including evaluation of the uncertainties in both measurement and distribution of these variables; (b) determining the distribution of fracturing within the controlled area and determination of the effects of fracturing on ground-water flow under undisturbed conditions; (c) determining flow directions and rates under undisturbed conditions within the controlled area, including both flow under "preshaft" conditions and an estimate of how long it will take flow conditions at the WIPP site to recover from the effects of shaft sinking and hydraulic testing; (d) determining fluid geochemistry and behavior of radionuclides in Culebra fluids and in mixtures of Culebra and repository fluids, including organic complexing agents; (e) determining the effects of fracturing, matrix diffusion, and sorption/precipitation on radionuclide transport in the Culebra under undisturbed conditions; and (f) refining the Culebra model.

Relevant Activities:

Lab:	S.4.1.1 (p. 2-168), S.4.1.2 (p. 2-169), S.4.1.3 (p. 2-170), S.4.1.4 (p. 2-171), S.4.1.5 (p. 2-172)
Modeling:	S.4.2.1 (p. 2-173), S.4.2.2 (p. 2-175), S.4.2.3 (p. 2-177), S.4.2.4 (p. 2-178)
In Situ:	S.4.3.1 (p. 2-179), S.4.3.2 (p. 2-180), S.4.3.3 (p. 2-181), S.4.3.4 (p. 2-182), S.4.3.5 (p. 2-183), S.4.3.8 (p. 2-186), S.4.3.9 (p. 2-187), S.4.3.10 (p. 2-188), S.4.3.11 (p. 2-189)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.3 Rustler/Salado Formation: (a) determining the time scales required for significant hydrologic interaction between the Salado Formation and overlying (and underlying) formations; and (b) extending Rustler Formation computational meshes to simulate the Salado/Rustler connection for screening scenarios.

Relevant Activities:

Lab:	None
Modeling:	S.3.2.5 (p. 2-147), S.4.2.1 (p. 2-173), S.4.2.3 (p. 2-177)
In Situ:	S.3.3.9 (p. 2-158), S.3.3.10 (p. 2-159), S.4.3.5 (p. 2-183), S.4.3.6 (p. 2-184), S.4.3.7 (p. 2-185)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.4 Rustler Formation: (a) estimating the regional distribution of relative permeabilities and head potentials among the several members within the Rustler Formation and between the Rustler Formation and saturated portions of the Dewey Lake Red Beds; and (b) selecting codes and developing computational meshes for scenarios requiring Rustler Formation hydrology.

Relevant Activities:

- Lab: None
- Modeling: S.4.2.1 (p. 2-173), S.4.2.3 (p. 2-177)
- In Situ: S.3.3.10 (p. 2-159), S.4.3.2 (p. 2-180), S.4.3.3 (p. 2-181), S.4.3.5 (p. 2-183)
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.5 Dewey Lake Red Beds: (a) determining the regional distribution of hydraulic saturation within the Dewey Lake Red Beds; and (b) extending Rustler Formation computational meshes for scenarios including Dewey Lake Red Bed hydrology.

Relevant Activities:

- Lab: None
- Modeling: S.4.2.3 (p. 2-177)
- In Situ: S.4.3.7 (p. 2-185), S.4.3.8 (p. 2-186)
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.6 Rustler/Dewey Lake Red Beds: determining the bounding directions and magnitudes of modern vertical fluid flow within the Rustler Formation and between the Rustler Formation and Dewey Lake Red Beds.

Relevant Activities:

- Lab: None
- Modeling: S.3.2.5 (p. 2-147), S.4.2.1 (p. 2-173), S.4.2.3 (p. 2-177)
- In Situ: S.3.3.10 (p. 2-159), S.4.3.2 (p. 2-180), S.4.3.3 (p. 2-181), S.4.3.5 (p. 2-183), S.4.3.7 (p. 2-185)
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.7 Castile Formation Brines: (a) estimating the distribution and time dependent fluid pressures and flow rates of Castile Formation pressurized brine occurrences at and near the WIPP site; and (b) estimating the timing and efficiency of borehole plugging.

Relevant Activities:

- Lab: None
- Modeling: S.4.2.2 (p. 2-175), S.4.2.4 (p. 2-178)
- In Situ: None
- PA: PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.8 Pressurized Brine Hydrofracturing and Transport: (a) evaluating the hydrologic behavior (including response of preexisting fractures) and the effects on radionuclide transport of changes in fracture properties within the Culebra Dolomite Member and the Dewey Lake Red Beds in response to injection of Castile Formation brine, over the geometric area extending from the point of brine injection to that where fluid-pressure heads and flow rates approximate those under undisturbed conditions, perhaps extending into the accessible environment; (b) evaluating the possibility of hydrofracturing within the Salado Formation as a consequence of Castile brine injection; and (c) incorporating the effects of brine injection in models for the Castile scenarios.

Relevant Activities:

Lab:	None
Modeling:	S.4.2.2 (p. 2-175), S.4.2.3 (p. 2-177), S.4.2.4 (p. 2-178)
In Situ:	S.4.3.7 (p. 2-185), S.4.3.8 (p. 2-186)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.9 Bell Canyon Flow and Geochemistry: (a) evaluating possible flow directions and rates between the Rustler and Bell Canyon Formations and within the Bell Canyon; (b) evaluating the available Bell Canyon Formation geochemical, hydrologic, and nuclide-transport data bases and augmenting the data bases as required; and (c) extending Rustler Formation computational meshes to simulate the Rustler/Bell Canyon connection for screening scenarios.

Relevant Activities:

Lab:	None
Modeling:	S.4.2.3 (p. 2-177)
In Situ:	S.4.3.6 (p. 2-184)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.10 Optimization: performing vertical and lateral resolution studies to optimize meshes for computational efficiency.

Relevant Activities:

Lab:	None
Modeling:	None
In Situ:	None
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.2.11 Composite Domain: linking the Los Medanos and local three-dimensional computational models on a composite domain for computational efficiency.

Relevant Activities:

Lab:	None
Modeling:	None
In Situ:	None
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Controlled Area Data Base

The current understanding of the controlled area is summarized as follows:

- Current values for the far-field permeability of the Salado Formation are in the range of 10^{-9} darcy, and it is not known if the Salado Formation behaves as a continuous hydrologic system in the far field.

- Recent modeling studies of Rustler/Culebra hydrology indicate a general southerly flow direction under modern undisturbed conditions.

- Culebra fluids are highly variable in composition and concentration of dissolved solids, ranging from relatively fresh water to brines half saturated with halite.

- The hydrologic and geochemical setting of the Rustler Formation at and near the WIPP facility is not at steady state and is responding to the cessation of recharge occurring 12,000 to 16,000 years ago.

- The Culebra transmissivity and head data bases will be adequate for performance assessment and the Culebra storativity data bases should be adequate for performance assessment modeling.

- Transmissivity of claystones/siltstones in the Forty-niner, Tamarisk, and the Unnamed Lower Members of the Rustler Formation are in the range of 2.4×10^{-10} to 7.6×10^{-8} meters^2/second. The transmissivity of the anhydrites of the Rustler are too low to measure successfully in the field.

- Vertical fluid flow between the Magenta and the overlying Forty-niner Member of the Rustler Formation is upward. In areas where the Dewey Lake Red Beds are unsaturated or too tight to measure, no potential exists for downward flow from the surface to Rustler carbonates.

- There appears to be potential for limited upward flow into the Culebra Dolomite Member from the Unnamed Lower Member, the Rustler/Salado contact zone, and at least a portion of the Salado Formation.

- Although important on the hydropad scale, the effects of fracturing are not significant to regional ground-water flow and performance assessment modeling for undisturbed conditions. Matrix diffusion plays a strong role in contaminant transport within the Culebra under these same conditions.

- The Dewey Lake Red Beds in the vicinity of the WIPP site appear to be hydrologically unsaturated. A limited number of private wells south of the WIPP site appear to produce water from "perched" zones within the unit.

- The Castile Formation contains highly pressurized brines both north and south of the WIPP site. Geophysical studies indicate that similar brines may be present beneath a portion of the WIPP waste-emplacement panels.

- At WIPP-12, fluid pressures at the surface, resulting from pressurized Castile brines, were approximately 200 psi, sufficient to drive saturated brine to the surface and have the potential to alter head gradients and flow directions/rates within the Culebra, at least temporarily, under a breach scenario.

- Fluid flow following an interconnection of the Bell Canyon and Rustler Formations would be downward, into the Bell Canyon.

Subelement 1.3.3 Hydrologic Transport Modeling

Appropriate computational models will be selected, adapted, and optimized for coupling with the hydrologic-flow computational models to simulate transport of radionuclides through the controlled area to the accessible environment.

Subelement 1.3.3 is addressed by performance assessment activities PA.3, PA.4, PA.5, PA.7, and PA.9. Information needs for this subelement include

1.3.3.1 Subdomains: identifying important subdomains for transport modeling.

1.3.3.2 Transport Mechanisms: identifying important transport mechanisms in the various hydrologic units identified in 1.3.4.1 for various scenarios.

1.3.3.3 Transients: determining whether transport models capable of simulating transient hydraulic conditions, including specialized modeling components such as a model for pressurized brine, are needed based on the results of scenario screening.

1.3.3.4 Transport Codes: selecting computational codes for transport in the controlled area.

1.3.3.5 Optimization: optimizing coupling between hydrologic and transport domains and optimizing transport computational efficiency.

Subelement 1.3.4 Borehole Plug Behavior and Modeling

This subelement concerns the behavior and long-term performance of plugs that would be emplaced in drilled boreholes within the controlled area during facility closure. It also concerns the potential for communication between boreholes and the repository and the flow rate of fluids that could transport radionuclides from the controlled area into the accessible environment, especially flow to the surface resulting from human intrusion into a Castile Formation pressurized brine occurrence.

Information needs for this subelement include

1.3.4.1 Borehole Plugging Material Behavior: determining how effective cement- or mineral-based grouts will be in restricting fluid flow and maintaining the grout's stability and properties in the various host rocks over the required time period. Host rocks considered must include the Castile Formation anhydrites and both carbonate and noncarbonate units within the Rustler Formation.

Relevant Activities:

Lab:	S.2.1.1 (p. 2-120), S.2.1.3 (p. 2-122)
Modeling:	S.2.2.2 (p. 2-124)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.3 (2-129)
PA:	PA.3 (p. 2-73), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.4.2 Borehole Plug Interactions: understanding the interaction between the plugging material and the host rock, including both salt and nonsalt units. The materials interactions will be examined to determine whether the borehole casing can be left in place while the plug is being installed.

Relevant Activities:

Lab:	None
Modeling:	S.2.2.2 (p. 2-124)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.3 (p. 2-129), S.3.3.1 (p. 2-150), S.3.3.2 (p. 2-151), S.3.3.3 (p. 2-152), S.3.3.10 (p. 2-159)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

1.3.4.3 Borehole Plugging Criteria, Concepts, and Designs: determining the requirements for borehole plugs, emplacement techniques, and plug performance as engineered barriers under the EPA Standard. Quantitative parameters for the plugging system at specific units in the stratigraphy will be established so that performance assessment can be completed and criteria, concepts, and engineering designs for borehole plugs can be developed.

Relevant Activities:

Lab:	None
Modeling:	S.2.2.2 (p. 2-124), S.3.2.5 (p. 2-147)
In Situ:	S.2.3.1 (p. 2-125), S.2.3.3 (p. 2-129)
PA:	PA.3 (p. 2-73), PA.4 (p. 2-75), PA.5 (p. 2-77), PA.7 (p. 2-80), PA.9 (p. 2-85)

Summary of Borehole Plug Data Base

Some of the characteristics of shaft and panel sealing materials are applicable to borehole plugging requirements. Previous assessments of borehole plugging requirements indicated that existing, open boreholes in the vicinity of the WIPP facility pose a negligible threat to the public (INTERA, 1981; Christensen et al., 1981; Stormont, 1984). Existing boreholes do not penetrate the WIPP underground workings; salt between the boreholes and the repository must be dissolved or hydrofractured by high fluid pressures before connection to the repository can occur. As a result, long-term performance of plugs is not required in the Salado Formation and a cementitious mixture can therefore be used as the principal plugging material in the short-term. The Bell Canyon testing program provides a data base for evaluating the performance of borehole plugging materials and the techniques for emplacement (Christensen and Peterson, 1981). Summary evaluations of borehole plugging materials, strategy, and concepts are contained in more recent documents (Stormont, 1988a; Tyler et al., 1988). However, additional studies are needed to develop adequate plugs for boreholes drilled in the Rustler Formation. These plugs must restrict fluid flow and radionuclide transport from the Culebra Dolomite Member to the surface in the event of human intrusion into a pressurized brine occurrence.

ELEMENT 1.4 Computational System

Consequence analysis of the complex WIPP disposal system, including evaluation of uncertainties for all significant scenarios, will entail up to 1,000 simulations, assuming 100 Monte Carlo simulations per scenario for 10 scenarios. Each simulation should be reproducible and available for examination. Distributions will be developed for each scenario, and for the 10,000-year performance, the distributions must be combined probabilistically. The many different, complex computational models will be linked and/or coupled and executed for each simulation. The system must be automated to complete the performance assessment in a reasonable time period. The analyst should be able to set up new calculations quickly. The data flow through the system should be reliable and not specific to the particular computational models, because different scenarios may require different models. A significant procedural element in performance assessment of geologic repositories is reducing the computational problem to manageable dimensions.

The data base is an integral part of the compliance assessment system. The data selected for the performance assessment must be of high quality. The primary data should be reduced, analyzed, and carefully quality controlled, and should involve minimal subjective interpretation. The primary data base must contain all data necessary for the compliance assessment. The secondary data base must be constructed from the primary data base by evaluating and interpreting the data to arrive at a conceptual model of the disposal system for each scenario to be simulated. Interpretation can require objective or subjective interpolation of data. Objective techniques are easily reproduced by others. However, subjective interpretation requiring extrapolation of data requires professional judgment and must be well-documented to allow reproduction by others. Selection and interpretation of the primary data for conceptual models are the starting points for simulation of significant scenarios for the consequence analysis. Activity PA.11 addresses the information needs for Element 1.4 (Computational System).

Subelement 1.4.1 Development of the Compliance Assessment System

The set of computational models assembled for the subsystems of the disposal system will be linked, coupled where necessary, and integrated into CAMCON, a modular system that automatically controls the simulation. CAMCON has been developed and initial tests are complete.

Information needs for this subelement include

1.4.1.1 Computer Codes: (a) evaluating available flow and transport codes for performance, user friendliness, running speed, quality assurance, and capabilities; and (b) calibrating or benchmarking codes selected.

1.4.1.2 Variable Mesh: (a) adding variable mesh capability to the system; (b) developing three-dimensional interpolators for domain decomposition for hydrology and/or transport codes, and if necessary, (c) rezoning transport computational subdomains.

1.4.1.3 Vertical Resolution: determining necessary vertical stratigraphic resolution between layers in the three-dimensional hydrologic-flow models.

1.4.1.4 Diagnostics: developing appropriate diagnostics for the system.

1.4.1.5 Sampling: adding a sampling module to the system.

1.4.1.6 Translators: adding input and output translators for each code, to keep the data base independent of the codes.

Subelement 1.4.2 Compliance Assessment Data Bases

The primary data provided by the characterization programs will be interpreted to develop a secondary data base that adequately describes an appropriate conceptual model of the disposal system for long-term simulation of each significant scenario.

Information needs for this subelement include:

1.4.2.1 Primary Data Assembly: assembling all the pertinent data from the disposal system characterization activities into the primary data base.

1.4.2.2 Primary Data Interpretation: objectively or subjectively interpreting the primary data to develop a secondary data base containing appropriate data sets to describe the various parameters required to simulate each of the scenarios.

ELEMENT 1.5 Consequence Analysis

Assessment of compliance with Subpart B of the Standard requires comprehensive consequence analyses. These analyses must provide quantitative predictions of the doses that could occur during the first 1,000 years and of the releases that could occur over the first 10,000 years. The numerical predictions will be based on complex computational models, analytical theories, and prevalent expert judgment. Elements 1.1 through 1.4 address the incorporation of judgment, theory, and models into the performance assessment. Element 1.5 represents the culmination of all the disposal system characterization efforts and the assessment methodology development. When the disposal system has been adequately characterized and modeled, conceptual models have been developed for the scenarios, uncertainties have been resolved to the extent possible, and the compliance assessment system is in place, two tasks will remain. These are a consequence analyses to predict the releases of radionuclides to the accessible environment resulting from both disturbed and undisturbed performance and to predict the doses that might occur from undisturbed performance.

Subelement 1.5.1 Containment Requirements

In Appendix B to the Standard, EPA describes the manner in which the quantitative comparison to the Containment Requirements should be made. "The (EPA) assumes that, whenever practicable, the (DOE) will assemble all of the results of the performance assessments to determine compliance with §191.13 into a complementary cumulative distribution function that indicates the probability of exceeding various levels of cumulative release. When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The (EPA) assumes that a disposal system can be considered to be in compliance with §191.13 if this single distribution function meets the requirements of §191.13(a)." Activities PA.8 and PA.10 address the information needs for Subelement 1.5.1.

Information needs for this subelement include

1.5.1.1 Scenarios and Probabilities: all scenarios of regulatory interest and their probabilities of occurrence for disturbed performance (as defined in Subpart B) of the disposal system for the first 10,000 years after disposal.

1.5.1.2 Conceptual Models: a conceptual model of the disposal system for each scenario.

1.5.1.3 Computational Models: a set of computational models for each scenario that will simulate behavior of the disposal system in response to that scenario.

1.5.1.4 Release Simulations: simulating behavior of the disposal system and developing a distribution of releases to the accessible environment for each scenario based on the parameter uncertainty in its conceptual model.

1.5.1.5 Complementary Cumulative Distribution Function: combining the releases and the associated scenario probabilities into a single complementary cumulative distribution function.

Subelement 1.5.2 Individual Protection Requirements

In Appendix B to the Standard, EPA describes the manner in which the quantitative comparison to the Individual Protection Requirements should be made. "When the uncertainties in undisturbed performance of a disposal system are considered, the (DOE) need not require that a very large percentage of the range of estimated radiation exposures ... fall below limits established in §191.15.... The EPA assumes that compliance can be determined based upon 'best estimate predictions' (e.g., the mean or the median of the appropriate distribution, whichever is higher)." Activities PA.8 and PA.10 address the information needs for Subelement 1.5.2; Activity PA.6 also addresses information needs 1.5.2.5 and 1.5.2.6.

Information needs for this subelement include

1.5.2.1 Scenario: the undisturbed behavior (as defined in Subpart B) of the disposal system for the first 1,000 years after disposal.

1.5.2.2 Conceptual Model: a conceptual model of the disposal system for undisturbed behavior.

1.5.2.3 Computational Model: a set of computational models that will simulate undisturbed behavior of the disposal system.

1.5.2.4 Release Simulations: simulating behavior of the disposal system and developing a distribution of releases to the accessible environment based on the parameter uncertainty in the conceptual model.

1.5.2.5 Pathway Simulations: simulating transport of released radionuclides through soil, water, air, and biota to man.

1.5.2.6 Doses: making the best-estimate dose prediction for each release distribution.

2.7 ACTIVITY DESCRIPTIONS

The Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant (Bertram-Howery and Hunter, 1989b) mapped the contribution of all existing activities (Table 2-1 of this plan) to the performance assessment. The current scientific program described in the Preliminary Plan is made up of activities that contribute directly to the Performance Assessment required to show compliance with the EPA Standard. Activities that could not be shown to contribute directly to the performance assessment have been dropped or are being phased out. Several activities have been modified in response to EPA, NAS/NAE WIPP Panel, and EEG review. The modifications have been incorporated into the activity descriptions.

This section provides brief descriptions of the specific activities that will be performed to obtain the information needed to support the five work elements described in Section 2.7.1 beginning on p. 2-30. Each activity description contains (1) a discussion of the focus of the activity, (2) the methodology that will be employed, and (3) a list of the information need or element addressed by the activity. For each information need or element listed, a reference number is given to allow cross-referencing with Section 2.7.1.

Activities directly related to the long-term performance assessment of the disposal system are described in Section 2.7.1. These activities are identified by the letters "PA" and sequential numbers for the 11 activities.

The supporting activities that provide conceptual models, input data, and model validation for the performance assessment are described in Section 2.7.2. The laboratory, modeling, and in situ activities are further divided into disposal room and drift system activities (Section 2.7.2.1), sealing system activities (Section 2.7.2.2), Salado Formation structural and fluid-flow activities (Section 2.7.2.3), and non-Salado hydrology and nuclide migration activities (Section 2.7.2.4). The supporting activities for these four technical areas are each identified by the letter "S" followed by a three-digit reference number. The first digit corresponds to the specific activity area (i.e., S.2._._ refers to a supporting activity in the sealing system category); the second digit is a 1 if the supporting activity is a laboratory study, a 2 if the supporting activity is a modeling activity, and a 3 if it is to be performed in situ. The third digit is the sequential number of supporting activities. For example, S.2.1.3 is the third laboratory activity of the sealing system area. Some of the supporting activities will also provide data that will be useful in showing compliance with RCRA. For example, some activities will examine whether hazardous waste components will degrade sealing materials (e.g., Activity S.2.1.1); gas data from the bin-scale and alcove tests will include measurements of VOCs (Activities S.1.3.2, S.1.3.3).

More detailed activity descriptions can be found in the Preliminary Plan (Bertram-Howery and Hunter, 1989b) and in individual test plans, which have been or are being prepared as appropriate.

2.7.1 Performance Assessment Activities

The 11 performance assessment activities described in this section are related to the development of scenarios and to an assessment of compliance with 40 CFR 191, Subpart B. The supporting activities that provide conceptual models, input data, and model validation for the performance assessment activities are described in Section 2.7.2.

Activity PA.1
SCENARIOS: Screening

1. Focus

   The events and processes retained to date (Hunter, 1989) will be further screened and used to prepare a set of scenarios for final probabilistic consequence analyses (Activities PA.8 and PA.10). Currently, the WIPP performance assessment program is expanding the methodology of scenario development and screening to include these additional conditions and restraints that result from a probabilistic standard, the most important of which is the clear definition of what constitutes a branch point within a flow diagram. A report explaining the evolution of the methodology and the development of a set of scenarios for initial probabilistic analyses will be published (Guzowski, 1990).

2. Methodology

   To perform preliminary modeling for the screening, existing models will be adapted to the scenario being examined, and bounds on consequences will be calculated. Results of screening these scenarios on the basis of probability, consequence, physical reasonableness, and regulatory interest will help determine whether other scenarios from the retained set will be examined and possibly screened. The scenario set retained for consequence analysis will be updated annually. Finally, the significant set of scenarios for final consequence analysis will be chosen.

3. Element Addressed

   Scenario Screening (1.1)

Activity PA.2
SCENARIOS: Probability Assignment

1. Focus

Consequences for each significant scenario are combined with scenario probabilities to produce a single complementary cumulative distribution function for release to the accessible environment. Calculated probabilities for events and processes which have been eliminated are included in the Hunter (1989) document. However, based on further research, it may become necessary to evaluate probabilities or to estimate probabilities for those events and processes which are retained and for as-yet unexamined events and processes.

Probabilities of occurrence of selected scenarios that survive screening on the basis of simple consequence analysis, either for further screening or for direct use in preparing a complementary cumulative distribution function, must be estimated.

2. Methodology

The procedure for estimating probabilities of occurrence for events and processes is part of scenario development and screening. During scenario development, events and processes are screened on the basis of physical reasonableness, probability, and regulatory guidance. Consequence modeling will be used to further screen the remaining scenarios. Some scenarios for which sufficient data on probability do not exist may survive screening by consequence modeling. If so, probabilities of occurrence for these scenarios probably will have to be estimated using expert opinion.

A number of procedures for estimating probabilities of occurrence are available (Hunter and Mann, 1989). Hunter (1989) has analyzed numerous events and processes of interest at WIPP and the available data to determine the applicability of each of the probabilistic techniques. More than one probability technique was applicable to some of the events and processes, but in other cases, probabilities must be assigned using expert opinion. If scenarios to which probabilities were assigned, and not calculated, survive screening on the basis of consequence, it may be appropriate to select a panel of experts to determine or estimate their probabilities of occurrence.

3. Element Addressed

Scenario Screening (1.1)

Activity PA.3
HYDROLOGIC MODELING: REGIONAL (LOS MEDANOS MODEL)

1. Focus

Modeling of regional and local ground-water flow is the basis of radionuclide-transport calculations (Activity PA.5). A number of activities provide direct and indirect support to regional and local hydrologic modeling for performance assessment.

Site characterization defines the local conceptual model and the present flow fields, synthesizes observational data into flow and material-property fields that help explain and reproduce the data, and establishes confidence in our understanding of the geology, hydrology, and geochemistry of the WIPP site. This conceptual model and present flow fields will be used as initial conditions from which simulations of the system are run far into the future (10,000 years) to perform the consequence and uncertainty analyses required by 40 CFR 191.

Past ground-water flow modeling has been concerned primarily with the Culebra Dolomite Member of the Rustler Formation in the immediate vicinity of the controlled area. An important measure of our understanding of the site is how well we can reproduce observations (e.g., pumping drawdowns) with model calculations. These calibrated model fields represent only an initial field in the 10,000-year simulation that must be carried out to assess compliance with 40 CFR 191. Over 10,000 years, processes that affect flow and transport within the accessible environment could occur at some distance vertically and laterally from the present characterized domain; therefore, the spatial extent of the modeling/observational survey domain will be enlarged to reduce uncertainty in the result.

The model domain has been enlarged laterally from 14.9 x 15.5 mi (24 x 25 km) to 21.1 x 24.8 mi (34 x 40 km) and vertically to eight layers as a first step. However, data are sparse within the larger model (called the Los Medanos model) domain in some key areas; both modeling and field surveys are needed to reduce uncertainties. Within the original domain, the vertical extent of the models and field data will be expanded beyond the Culebra Dolomite Member. A three-dimensional model of the Rustler and younger formations is necessary, because scenarios include potential hydrologic transport to (and leakage from) the Magenta Member. Some scenarios also include the Dewey Lake Red Beds. These vertical model extensions require additional field data and modeling to reduce uncertainties in calculated releases.

The Los Medanos model is a "first-step," three-dimensional, conceptual model. The present numerical code used for simulations is SWIFT II. Domain size is 21.1 x 24.8 mi (34 x 40 km) with eight vertical layers. The Culebra Dolomite Member of the Rustler Formation represents one computational layer of the model. Mesh optimization, vertical resolution studies, and coupling with transport models on appropriate subdomains will be performed before final consequence analysis.

2. Methodology

Reducing uncertainty in lateral boundary conditions is important. Data along the computational domain boundaries are sparse in key areas. To improve simulations of ground-water flow, primarily by reducing boundary uncertainties, the following studies are useful:

- Determine areal extent of Culebra-Magenta hydraulic connection.
- Determine hydrologic parameters of the Dewey Lake Red Beds.
- If transport calculations show that these parameters are important, estimate fracture frequency and orientation (vertical versus horizontal) within the Culebra Dolomite Member.
- Expand the fluid-density data base to fill in areas in field maps where data are sparse.
- If initial 10,000-year modeling shows that boundary conditions are significantly affecting the results, fill out data coverage for remaining boundary conditions (Clayton Basin, eastern boundary, and southwest boundary at Balmorrhea-Loving Trough).
- Study paleoclimate.

As additional data become available, the Los Medanos model will be used to calibrate an updated numerical model and to provide fields for sensitivity analyses, benchmark simulations for code comparisons, and mesh studies. Ultimately, the Los Medanos model will simulate ground-water flow for consequence analyses.

3. Element Addressed

Controlled Area: Behavior Characterization
and Performance Modeling (1.3)

Activity PA.4
HYDROLOGIC MODELING: LOCAL

1. Focus

Modeling of regional and local ground-water flow is the basis for radionuclide-transport calculations. A number of activities provide direct and indirect support to hydrologic modeling for performance assessment. A ground-water flow model of the local hydrology for use in the preliminary and final consequence analysis must be established.

Site characterization has focused primarily on the Culebra Dolomite Member within and near the controlled area. This member is now well characterized; the SWIFT II code has been calibrated (in two dimensions) on the conceptual model and data. The calibrated fields provide a benchmark against which other models and/or meshes will be tested. As previously noted, scenarios also include the Magenta Dolomite Member and Dewey Lake Red Beds.

2. Methodology

The local model will be extended in three dimensions, and the three-dimensional local model will extend through the Rustler Formation for most scenarios. Therefore, studies examining the potential for vertical fluid flow within the Rustler Formation would be useful.

The extension of the local model to three dimensions has several subtasks. One is to choose appropriate codes and develop meshes for those scenarios requiring only Rustler hydrology. A second subtask is to extend Rustler codes and meshes for those scenarios that include Dewey Lake Red Beds hydrology. A third subtask, probably needed only in the scenario-screening stage, is to extend Rustler meshes to address the Salado-Rustler connection. This last subtask also includes: (1) applying existing models to the site characterization conceptual model and incoming data from Subtasks 1 and 2, (2) studying vertical and lateral resolution to optimize meshes for computational efficiency, and (3) designing scenario-dependent calculations.

Some scenarios require additional data on the local scale. These scenarios examine the Salado and Bell Canyon Formations and pressurized brine occurrences in the Castile Formation. For the Salado and Bell Canyon Formations, hydrologic properties and radionuclide retardations are needed. These data will be used primarily in scenario screening, but Salado data are also needed for the repository/shaft systems model which will be used in some final scenario-dependent release calculations. These near-field data will need to be less uncertain than the others.

Because geophysical evidence indicates the possible presence of pressurized brine occurrences beneath the repository horizon (Earth Technology, 1988), and because it is difficult to rule out the existence of such features with absolute certainty, pressurized brine occurrences are important in several human-intrusion scenarios. Data on pressurized brine occurrences include volume, pressure, chemistry, and geometry. If the brine chemistry of these pockets is much different from brines expected to resaturate the rooms, the source term will have to be modified to include them after a borehole breach. However, it should be possible to define a standard brine for possible reservoirs based on existing data from other locations. Pressure will also be estimated from data on other pressurized brine occurrences. Sizes and volumes will be estimated from geophysical surveys.

3. Element Addressed

Controlled Area: Behavior Characterization
and Performance Modeling (1.3)

Activity PA.5
TRANSPORT MODELING

1. Focus

The release and dose calculations required to assess compliance with 40 CFR 191 cannot be completed without transport models. A number of activities provide direct and indirect support to transport modeling for performance assessment.

Three types of studies relating to the transport of radionuclides through geologic formations are needed. The first identifies important transport mechanisms in the various scenarios being considered and thus guides the selection of models and codes used for the consequence analysis. This study would ensure that the models and codes selected correctly simulate the relevant physical and chemical processes. The second type of study actually selects codes. This study assesses the capabilities, benchmarking, verification, and validation of various codes. Codes selected in this manner will have the most appropriate capabilities and also will provide confidence that they meet the WIPP quality assurance standards. The third type of study optimizes the implementation of the selected codes. The study will facilitate and streamline the actual computations during consequence analysis.

2. Methodology

This effort will consist of three tasks:

a. Identify the types of models and codes needed.

- Perform sensitivity analysis of radionuclide transport in transient ground-water flow fields to determine whether transport models with transient capability are needed.
- Determine which transport mechanisms (porous versus fracture, equivalent porous versus dual porosity) are important in the Culebra Dolomite Member for each of the various scenarios.
- Identify important subdomains for transport modeling.

b. Select codes.

- Assess capabilities of potential codes and compare with code requirements for performance assessment.
- Assess codes' benchmarking, verification, and validation.
- Select final codes for use in WIPP performance assessment and modify, if necessary.

c. Optimize transport computations for consequence analysis.

- Optimize coupling between hydrologic (Activities PA.3 and PA.4) and transport domains.

- Optimize computational efficiency for selected transport codes.

Data needs are retardation of radionuclides, porosities, fracture geometry, dispersion coefficients, and water chemistry in all geological units through which transport might be expected, e.g., Rustler Formation, especially the Culebra Dolomite Member; Dewey Lake Red Beds; and Salado Formation. In the geologic formations and their members, data on spatial variability in material properties and brines are also needed.

3. Elements Addressed

Repository/Shaft System: Behavior Characterization
and Performance Modeling (1.2)
Controlled Area: Behavior Characterization
and Performance Modeling (1.3)

Activity PA.6
PATHWAYS/DOSIMETRY

1. Focus

Compliance with 40 CFR 191 on individual protection requires predictions of doses during the time period from repository closure to 1,000 years for undisturbed performance of the repository. Although releases to the accessible environment in 1,000 years are not expected, dose calculations may be necessary because: (1) 40 CFR 191 has been remanded and its future is uncertain, and (2) releases to the accessible environment from undisturbed performance, while not expected, have not been ruled out.

The objective is to include pathways and dosimetry models in CAMCON (CAMCON is an automated system to manage the many simulations to be performed for the preliminary and final consequence analyses) and prepare corresponding data bases if dose calculations are needed for assessing compliance with individual protection regulations or for responding to possible results of the 40 CFR 191 remand.

2. Methodology

Two types of models are needed: biological pathways models and human dosimetry models. Biological pathways models are numerous and well documented. Two such models have been selected and will be adapted to WIPP scenarios and included in CAMCON. Historical data for these models are also plentiful. These data are the result of extensive biological and environmental surveys of the WIPP site and vicinity. The data will be collected in summary form for the appropriate pathways and computerized.

Human dosimetry models are also numerous and well documented. Appropriate dosimetry models have been selected for use in CAMCON. Their underlying data bases will be updated depending on radionuclide inventories.

3. Element Addressed

Consequence Analysis (1.5)

Activity PA.7
REPOSITORY/SHAFT SYSTEM MODELING

1. Focus

The behavior of the repository/shaft system must be understood sufficiently to simulate migration of radionuclides out of the repository to support Activities PA.6, PA.8, and PA.10. A large number of activities provide direct and indirect support to the modeling of the repository/shaft system using simple or complex models.

2. Methodology

An efficient, fast computational model or system of models for the simulation of repository/shaft behavior is needed. The repository/shaft system model will comprise a system of linked computational models:

a. Models of the rooms (closure, resaturation, waste containers, room chemistry, backfill, and retardation).

b. Models of the panel drifts and seals (flow and transport through seals, annular flow around seals, flow through surrounding disturbed rock zone, disintegration and/or fracturing, adjacent backfills, resaturation, closure, chemistry, and retardation).

c. Models of the drifts from panel seals to shafts (backfill, disturbed zone, resaturation, closure, brine chemistry, and retardation).

d. Models of the shafts and seals (flow and transport through and around the disturbed rock zones and seals, brine chemistry, retardation, and seal disintegration or fracture).

CAMCON will be the package for controlling this system's model during analyses performed to characterize sources in overlying formations for some scenarios.

The room model provides the source term for transport calculations. The room model will include the coupled effects of the waste containers and contents, backfill (including any chemical additives), gas generation, room closure, resaturation, retardation, and repository chemistry. Some of these components have been extensively modeled, but no attempt has been made to couple models into a complete package. To the extent possible, this coupling will be performed and tested. For performance assessment purposes, the room model will be studied and possibly simplified. The data needs, as presently conceived, are included in Table 2-2.

The model of panel drifts and seals will simulate flow and transport through and around the panels and seals, flow through the surrounding disturbed zone (accounting for resaturation), retardation in these materials (accounting for near-field brine chemistry), and possible degradation of the seals. For the adjacent backfill materials, the model should include the mixture with any chemical additives, material properties, effects on reconsolidation, resaturation, and retardation, and

Table 2-2. Models for Repository/Shaft Systems Simulation and Associated Data Needs

Data	Models			
	Room	Panel Drifts/ Seals	Drifts from Panel Seals to Shafts	Shaft/Seals
Source:				
Repository chemistry	X			
Inventory	X			
Concentrations of radionuclides in brine	X			
Volume of brine transferred	X			
Migration rate	X			
Backfill:				
Mixture	X	X	X	X
Porosity	X	X	X	X
Permeability	X	X	X	X
Waste Containers and Contents:				
Response to closure and brine inflow	X			
Room Closure Rate	X			
Gas Generation:				
Rate	X			
Pressure	X			
Resaturation (brine inflow rate)	X	X	X	X
Disturbed Rock Zone:				
Porosity vs. distance		X	X	X
Brine/gas permeabilities vs. distance	X	X	X	X
Transport:				
Retardation due to backfill materials	X	X	X	X
Retardation due to seal materials		X		X
Retardation due to host rock	X			X
Geometry	X	X	X	X
Final Consolidation State	X	X	X	X
Seals:				
Porosity		X		X
Permeability		X		X
Reliability (failure modes)		X		X

dissolution and precipitation. The data needs, as presently conceived, are included in Table 2-2.

The model of the drifts from the northernmost panel seals to shafts will simulate flow and transport from the panel seals adjacent to the storage area to the shaft repository-level seals, accounting for creep closure, geometry, backfill, repository chemistry, retardation, and the disturbed rock zone. Presently conceived data needs are similar to Table 2-2.

The model of the shaft and seals will simulate flow and transport through the shafts and their seals from the repository horizon to the scenario-dependent discharge horizon, e.g., the Culebra Dolomite Member of the Rustler Formation. The model will include flow through and around seals and backfill, flow through the disturbed rock zone, brine chemistry, retardation due to backfill, seal, and matrix materials, effects of seal disintegration and fracture, and dissolution and precipitation. Simulations will include flow down the shaft from leakage of overlying aquifers and flow with transport up the shaft required by various room pressurization scenarios. The presently conceived data needs are similar to Table 2-2.

The Salado component of the repository/shaft system model is an encompassing hydrologic model covering the larger zone of influence that drains during the resaturation period. This Salado component will be connected to the three-dimensional local model, so that potential Rustler-Salado vertical leakage will be included for scenario screening. A simplified version of the repository/shaft model will be embedded within the Salado component for scenario screening. Hydraulic properties and chemical interaction of radionuclides with rock matrix will be needed.

This system of models will interface with the larger CAMCON performance assessment system that includes geologic, hydrologic, and transport models. Many of the processes listed above are studied with various individual models. Some models are detailed, complex, finite element models for understanding processes and data, while other models are simplified for performing parameter variation studies that are useful for facility design. Therefore, some models may be more complex than needed for performance assessment and may be simplified, while others need to be enhanced to be adequate for the performance assessment application. These models will be adapted to performance assessment and included in a systems model of the repository and shafts.

3. Elements Addressed

Repository/Shaft System: Behavior Characterization and Performance Modeling (1.2)
Controlled Area: Behavior Characterization and Performance Modeling (1.3)

Activity PA.8
PRELIMINARY CONSEQUENCE ANALYSIS

1. Focus

Preliminary consequence modeling will allow the WIPP Project to assess the availability of data, techniques, and codes necessary to produce the release and dose calculations required to demonstrate compliance with 40 CFR 191 (Activities PA.6 and PA.10).

Preliminary consequence analysis is the process of setting up the calculation sequence, using CAMCON for each significant scenario. Preliminary release calculations are combined with probabilities to produce complementary cumulative distribution functions that scope the extent of the problem in the compliance-assessment step.

2. Methodology

All scenarios retained after screening (Activity PA.1) will be examined by the preliminary consequence analysis. However, the process of setting up the calculation sequence for each scenario is complex and time consuming, so scenarios may be grouped by commonality of modeling approach. For example, scenarios that can be analyzed by the same mesh would appear in the same group.

The preliminary groupings are the undisturbed scenario, the climate-hydrology-repository-shaft scenario group, and the human-intrusion scenario group. Early calculations will be repeated when revised models and additional data are obtained.

Conceptual models must be defined for each group. In developing these models, several items must be addressed:

- Sampling techniques will be compared to assure credibility and determine whether Latin hypercube sampling is the optimum sampling technique for these scenarios.

- Because each scenario is a sequence of events and processes, the order and time of occurrence of the event may be important to the calculated releases.

- Care must be taken to choose parameters that are sensitive, with ranges and distributions sufficiently known that the results will be realistic. These decisions will be based on sensitivity analyses.

- It is possible that analysis of some scenarios will require specialized modeling components. For example, the examination of human intrusion may require a model of pressurized brine occurrences.

After scenarios are grouped, codes selected, meshes defined, calibrated initial fields developed, and the input parameter space to be sampled identified, the preliminary consequence analysis calculations can be made. Preliminary complementary cumulative distribution functions will be produced so that potential problems can be identified during this stage of the work. The complementary cumulative distribution functions calculated during this preliminary work will be incomplete, because each will represent only one or a few scenarios. Some data will not yet be available but important sensitivity analyses for designing scenario-dependent computational strategies will continue. Therefore, the complementary cumulative distribution functions will be used only for scoping purposes. Dose calculations will also be made. Biological pathways and human dosimetry models are being included in CAMCON.

This activity will identify any deficiencies in the WIPP performance assessment methodology and correct or supplement the methodology as necessary before final consequence analysis begins.

3. Element Addressed

Consequence Analysis (1.5)

Activity PA.9
SENSITIVITY ANALYSIS

1. Focus

Sensitivity analyses will be performed on the scenarios and on various parts of scenarios, on component subsystems, and on systems during the preliminary consequence analysis (Activity PA.8) to determine where additional data are needed and where computer code efficiency can be improved or where sufficient data have been acquired. Four reports will be published by mid-FY90 that include sensitivity analyses. First, the sensitivity analyses performed during the history of the WIPP Project will be compiled into a review report which will indicate present status and how these results relate to the performance assessment system (Anderson, et al., 1990). Second, the Methodology Demonstration report (Marietta et al., 1989) will include simple sensitivity analysis results. Third, sensitivity analyses related to assessing the importance of uncertain boundary conditions, recharge, vertical connection, and climate variability for scenario screening will be reported (Marietta et al., 1990). Fourth, sensitivity studies will also focus on critical parameters such as radionuclide solubilities and permeabilities and porosities in the room, seals, MB139, and zones of the Culebra, and radionuclide retardations (Rechard et al., 1990). Room parameter variability will cover some proposed engineering modifications.

2. Methodology

Unlike uncertainty analysis, sensitivity analysis is not an explicit requirement of the Standard, but is a technique to understand and gain insight into the system. Hence, its primary usefulness is in the early phases of an assessment. An analyst may perform sensitivity analysis on individual module components or the system as a whole. Sensitivity analysis of an individual module allows an analyst to more fully understand the physical processes it represents. Sensitivity analysis of the whole system gives an analyst insight into the relative importance of modules and physical processes they represent and into the whole system in determining the performance measure. Sensitivity analysis identifies important parameters by quantitatively determining variation in model output that results from a specified variation in a submodel or model input parameter. Both the submodels and the master systems model, which links the submodels, will be examined to identify important parameters, whose range and distribution need to be known precisely, and unimportant parameters, which do not affect the results and need not be known with great precision.

Sensitivity analysis of the submodels will be completed within the experimental programs. Sensitivity analyses of the whole system will be completed within Activity PA.9 and will show which of the submodels are important.

Sensitivity analyses performed during the preliminary consequence analysis (Activity PA.8) will identify means of correcting deficiencies in the methodology or in the disposal system itself before the final consequence analysis.

There are three primary areas of sensitivity analysis:

a. Comparison of Sensitivity Analysis Methods for Computer Codes: Sensitivity analyses of computer codes can be performed using a response-surface methodology based on input determined from fractional factorial design, Latin hypercube sampling with and without regression analysis, differential analysis, adjoint and Green's function techniques, and the Fourier amplitude sensitivity test. The choice of approach will be based on the ease of implementation, flexibility, estimation of the cumulative distribution function of the output, and adaptability. For such a complex system of computer codes to be used in the WIPP performance assessment, a variety of techniques will probably have to be used. Care will be used to assure that the complexity of the sensitivity-analysis technique is appropriate where implemented.

b. Sensitivity Analysis of Geohydrologic System and Transport: The geohydrologic transport component of the performance assessment system can be separated from the repository/shaft part of the system. The geohydrologic component has defined the initial fields so that, given a source, the combined geohydrologic transport component can calculate the performance measure.

   Sensitivity analysis of this component will

   - Assess computational, physical, and chemical parameter sensitivities,

   - Assess effects on the flow field and transport of brine density variations, pumping, injection, recharge, material and hydrologic data gaps, and boundary conditions, and

   - Identify important processes and data for the analysis of the various scenarios.

c. Sensitivity Analysis - Repository/Shaft System: The repository/shaft component of the performance assessment system can be run as a separate systems analysis for performance assessment. The repository/shaft systems model will use CAMCON as a separate application. Its components will probably be room, panel and drifts, and shafts and seals models (Activity PA.7). Some calculations will require embedding parts of this system within a Salado or Salado-Rustler component.

   Sensitivity analysis of this component will

   - Assess computational, physical, and chemical parameter sensitivities,

   - Identify important parameters for the analysis of the various scenarios, and

   - When appropriate, simplify complex models used by the facility design group for use by performance assessment.

- Examine the effects on the repository system of proposed engineered alternatives from Activity S.1.2.5.

The latter item is an important step in the repository/shaft model case because mechanical, resaturation, source, and transport models are complex and finely meshed compared to performance assessment needs. CAMCON will accept these codes, but simplification, primarily in meshing, would lower running times. However, important processes within the whole system must be identified and retained and cannot be sacrificed just for the sake of simplification. This task is a methodical procedure for adapting individual complex models to performance assessment needs by assembling a repository/shaft systems model through CAMCON. The model will be interfaced with the geohydrologic transport model through the larger CAMCON performance assessment application.

3. Elements Addressed

Repository/Shaft System: Behavior Characterization and Performance Modeling (1.2)
Controlled Area: Behavior Characterization and Performance Modeling (1.3)

Activity PA.10
FINAL CONSEQUENCE ANALYSIS

1. Focus

For assessing compliance of WIPP with the Containment Requirements of 40 CFR 191, Subpart B, consequence analysis must be performed for each scenario that is determined to be significant during scenario screening. The results of the release analyses must be assembled and represented in the form of a single complementary cumulative distribution function, which will then be compared with the Standard.

2. Methodology

Final consequence analysis will examine the same scenarios and use the same codes and techniques used in the preliminary consequence analysis, with two exceptions. Any scenarios that have been shown to contribute negligibly to the complementary cumulative distribution function may be omitted from the final consequence analysis. Any codes or techniques that have shown deficiencies during the preliminary analysis will be corrected before the final analysis. In addition, the final consequence analysis will have access to additional and improved data not yet available for the preliminary consequence analysis.

This activity comprises several tasks:

a. Finalizing all data and models so they can be used in the final consequence analysis.

b. Processing all scenarios through CAMCON and analyzing the results.

c. Combining scenario consequences with probabilities to produce the final complementary cumulative distribution function, and then comparing the complementary cumulative distribution function with Section 191.13, Containment Requirements, of the Standard. In addition, if there is a release of radionuclides predicted to result from undisturbed repository performance during the first 1,000 years, doses will be calculated and compared with Section 191.15, Individual Protection Requirements, of the Standard.

3. Element Addressed

Consequence Analysis (1.5)

Activity PA.11
DEVELOP PRIMARY DATA BASE

1. Focus

Performance assessment calculations (Activities PA.6, PA.8, and PA.10) require a dedicated primary data base which must be interfaced with CAMCON. Data will continue to be collected from the experimental and design activities described in this Plan and must be integrated into the data base.

2. Methodology

The primary data base comprises those observed data selected to be used in the performance assessment. These data are analyzed and reduced. Data reduction, assembly, and interpretation is a complex task.

Primary data will be objectively or subjectively extended to regular grid information and placed into the secondary data base, where they can be directly accessed by the various model components of CAMCON. The primary data base is the foundation of a credible consequence analysis. These observed, experimental, and design data are supported by other WIPP programs through reports, scientific publications, and quality assurance. Therefore, performance assessment use of these data is critically important and must follow prescribed quality assurance procedures. To accomplish this task, a data base management system will be prepared.

3. Element Addressed

Computational System (1.4)

2.7.2 Supporting Activities: Disposal System Characterization

This section describes supporting activities either underway or proposed for implementation during the Test Phase and continuing until compliance with the EPA Standard is satisfactorily demonstrated. Scientific investigations of technical issues related to safe isolation of nuclear wastes in bedded salt have been conducted as part of the WIPP Project since 1975 (e.g., Matalucci et al., 1982; Lappin, 1988; Tyler et al., 1988; and Lappin et al., 1989). These studies have resolved many technical issues and have focused attention on aspects still requiring investigation. The promulgation of the EPA Standard, 40 CFR 191, and RCRA, 40 CFR 268, has also helped to delineate areas of study that require more extensive data to assure adequate confidence in WIPP's isolation performance.

There are four major technical areas to address Elements 1.2 and 1.3:

The disposal room and drift system activities will address the interaction of TRU waste and backfill in a waste room with the surrounding rock. The combined interactions of the source term, waste containers, emplaced backfill and admixtures, brine inflow, and gas generation are studied through laboratory testing, modeling, and in situ testing. The behavior and performance of possible backfills and additives to be emplaced in access drifts as part of facility decommissioning are also being investigated.

The CH-TRU waste gas generation tests are an important part of the in situ test program at WIPP. These tests will extend laboratory data sets (which are collected on simulated waste) to CH-TRU waste and will provide real-waste data to validate model predictions of gas generation as a function of water content, waste heterogeneity, gas and water getters, backfills, etc., in the room; and transport out of the room. Planned and existing laboratory tests will bracket the times and conditions of interest for each important gas (H_2, CO_2, N_2) for 10,000 years. Bin-scale tests containing approximately six drums per bin of the appropriate CH-TRU waste, backfill materials, getters, and brine are planned to provide a real waste, synergistic test that complements the laboratory tests for those repository conditions found to be important. Finally, the alcove tests will provide data required to validate the gas generation models that will be developed from laboratory- and bin-scale tests. These models will be the basis of performance assessment models. The results will show whether predictions bracket the measured responses and thus determine, at least partially, whether the models and data sets are adequate to predict long-term behavior of the gases in the repository. Finally, although bin-scale and alcove tests will be initiated with the current design-basis waste and backfill, engineering modifications of the waste and backfill may be tested in Phase 3.

The sealing system activities involve seal design, system behavior, and overall performance evaluation. Seals will be developed for use in drifts to isolate waste panels, in access shafts to isolate the repository from the accessible environment, and in exploratory boreholes. Laboratory and in situ tests will evaluate behavior of potential seal materials such as crushed salt, salt/clay mixtures, and concretes.

Studies of structural and fluid-flow behavior of the Salado Formation should improve the capability to model fluid flow, hydrologic transport, waste room and drift response, and shaft closure. Healing of fractures in the disturbed zone outside excavations and around seals in shafts and access drifts is evaluated. Effects of brine on salt creep are examined. Laboratory and in situ tests provide data for improving models of excavation closure, fracture behavior, permeability, and fluid-flow characteristics of the Salado Formation, and brine inflow to excavated rooms. A wide range of studies addresses the behavior of penetrations through the Salado Formation, openings at the repository level, and fluid flow to and through these disturbances in the host rock.

The non-Salado hydrology and radionuclide migration activities will address transport of waste to the Rustler Formation and in the Rustler Formation under present and future conditions. Laboratory studies of sorption and retardation in the Rustler Formation are included, as well as in situ geophysical and hydrological tests from the surface.

Activities within the four major areas will be conducted during the Test Phase according to the overall assignment of priority based on data needs for seal-system design and performance assessment. Most in situ supporting activities described in this chapter are conducted in the northern part of the WIPP underground and in the Air Intake Shaft. The CH-TRU gas generation tests are to be conducted in the southern part of the underground facility and will provide full-scale confirmation of the previous laboratory and simulated-waste tests.

The discussions of the four activity areas which follow each contain (1) an activity flow diagram, (2) an activity matrix table, and (3) descriptive narratives. The activity matrix lists the activities and their applications to specific phenomena and parameters that will be examined. Each descriptive narrative describes the focus of the activity, the methodology to be used to perform the activity, and the information needs it supplies. The activities of each program area are further separated into: (1) laboratory studies, (2) modeling studies, and (3) in situ tests.

2.7.2.1 Disposal Room and Drift System Activities

The disposal room and drift system activities (Table 2-3) focus on (1) interim or transient-state structural and fluid-flow behavior of waste and backfill; (2) the final state of waste entombment and how rapidly it will be achieved (in collaboration with the seal system activities described in this chapter); (3) design of the backfill for the drift system to further assure isolation of the waste; and (4) estimates of the time-dependent source term for release and migration of radionuclides and hazardous components, with and without human intrusion. The activities in this section represent final integration of various individual and often independent components of the disposal system. Integration is accomplished by systems analyses that determine how the components respond in concert (Tyler et al., 1988), leading to comprehensive models (Activity S.1.2.4) for evaluating the long-term performance of the repository system.

Table 2-3. Applications of the Disposal Room and Drift System Investigations

Program-Area Activity	Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.1.1 Laboratory Studies:				
S.1.1.1 Backfill-Mix Creep and Permeability Behavior	Room Closure, Brine Distribution	Seal Permeability*		
S.1.1.2 Backfill-Mix Selection Tests	Getter Effectiveness, Backfill Performance			
S.1.1.3 Drum and Box Mechanical Response	Container Collapse, Room Closure, Waste/Backfill/Brine/ Room Interactions			
S.1.1.4 Repository Chemistry	Source Term Chemistry, Gas Generation, Backfill Performance			
S.1.1.5 Radionuclide Chemistry	Source Term Chemistry, Radionuclide Solubility			
S.1.2 Modeling Studies:				
S.1.2.1 Backfill-Mix Consolidation Model	Backfill Performance	Seal Permeability*		
S.1.2.2 Drum and Box Collapse Models	Room Closure, Container Collapse			
S.1.2.3 Backfill-Mix Selection Analysis	Room Closure, Drift Seal Performance			
S.1.2.4 Disposal Room Performance Model	Room Closure			

*Denotes a secondary application

Table 2-3. Applications of the Disposal Room and Drift System Investigations (Concluded)

Program-Area Activity	Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.1.2.5 Engineered Alternatives	Systems Stability			
S.1.2.6 Additional Development of EQ3/6	Radionuclide Solubility			Radionuclide Solubility, Radionuclide Transport*
S.1.3 In Situ Tests:				
S.1.3.1 Simulated TRU Testing (Rooms T and J)	Waste/Room Interactions, Backfill Performance			
S.1.3.2 Alcove Gas Generation Tests	Waste/Room Interactions, Gas Generation, Backfill Performance			
S.1.3.3 Bin-Scale Gas Generation Tests	Gas Generation, Backfill Performance, Getter Effectiveness			

*Denotes a secondary application

Information from a number of activities will be used to select backfill and to model entombment of the disposal room contents. Most obvious are the rate of room closure (or possible expansion in response to gas pressurization) (Activity S.1.2.4), the compaction properties of the room contents (Activities S.1.1.1 to S.1.1.3, S.2.1.2, and S.2.1.3), and the rate of brine seepage into the room (Activities S.3.2.4, S.3.3.5, S.3.3.6, S.3.3.8 and S.3.3.9). Results from these activities will be combined to predict (1) time-dependent bounds on void volumes and fluid permeabilities of design-basis and modified waste and backfill in the rooms and drifts during compaction, (2) the rate at which the voids may become saturated or rates at which net gas generation may force gas into the surrounding rock, (3) the final permeability of the resaturated rooms, drifts, and surrounding disturbed zone (Activity S.3.2.6), and (4) the net interaction (Activity S.1.2.4) of gas, brine, and structural behavior in controlling the source term for migration of radionuclides and hazardous chemicals from the WIPP (Activity S.1.2.4). This prediction must integrate the results of laboratory (Activities S.1.1.4, S.1.1.5), bin-scale (S.1.3.3), and alcove (S.1.3.2) tests. Similar considerations in modeling seal performance can be found in Stormont and Arguello (1988).

Predictions of change in the state of waste entombment with time also depend on source-term predictions (the amount and mobility of the radioactive species and gases produced by waste decomposition). Source term activities quantify the chemical behavior of the disposal rooms (Activity S.1.1.4), predict radionuclide solubilities in concentrated brines (Activity S.1.1.5), and model radionuclide solubilities (Activity S.1.2.6). This information must be available to assess the mobility of the radionuclides under disturbed or undisturbed conditions.

The room behavior model will represent an understanding of a number of complex interactions. Data will be collected for the behavior of each component in the room and on the interactions of room closure, room backfill, drum collapse, gas generation, and brine inflow. Although all interactions and data sets may not be completely defined, sufficient data will be collected to allow expert judgment to define the models and data used in the performance assessment.

A flow diagram (Figure 2-5) illustrates how the activities in this program and information from other program areas are combined. First, laboratory tests and models of backfill consolidation are needed to select a backfill for the disposal rooms and the drift system. After a backfill is prescribed (Activity S.1.2.3), its mechanical response to closure is combined with the waste container collapse data (Activity S.1.1.3) and model (Activity S.1.2.2) to develop the disposal room performance model (Activity S.1.2.4). Best estimates of source characteristics, room closure, brine inflow, and gas formation are needed at various stages of model development. Experiments with CH-TRU waste and simulated wastes (Activities S.1.3.1, S.1.3.2, and S.1.3.3) will provide as complete in situ data as possible for partial validation of repository-system models.

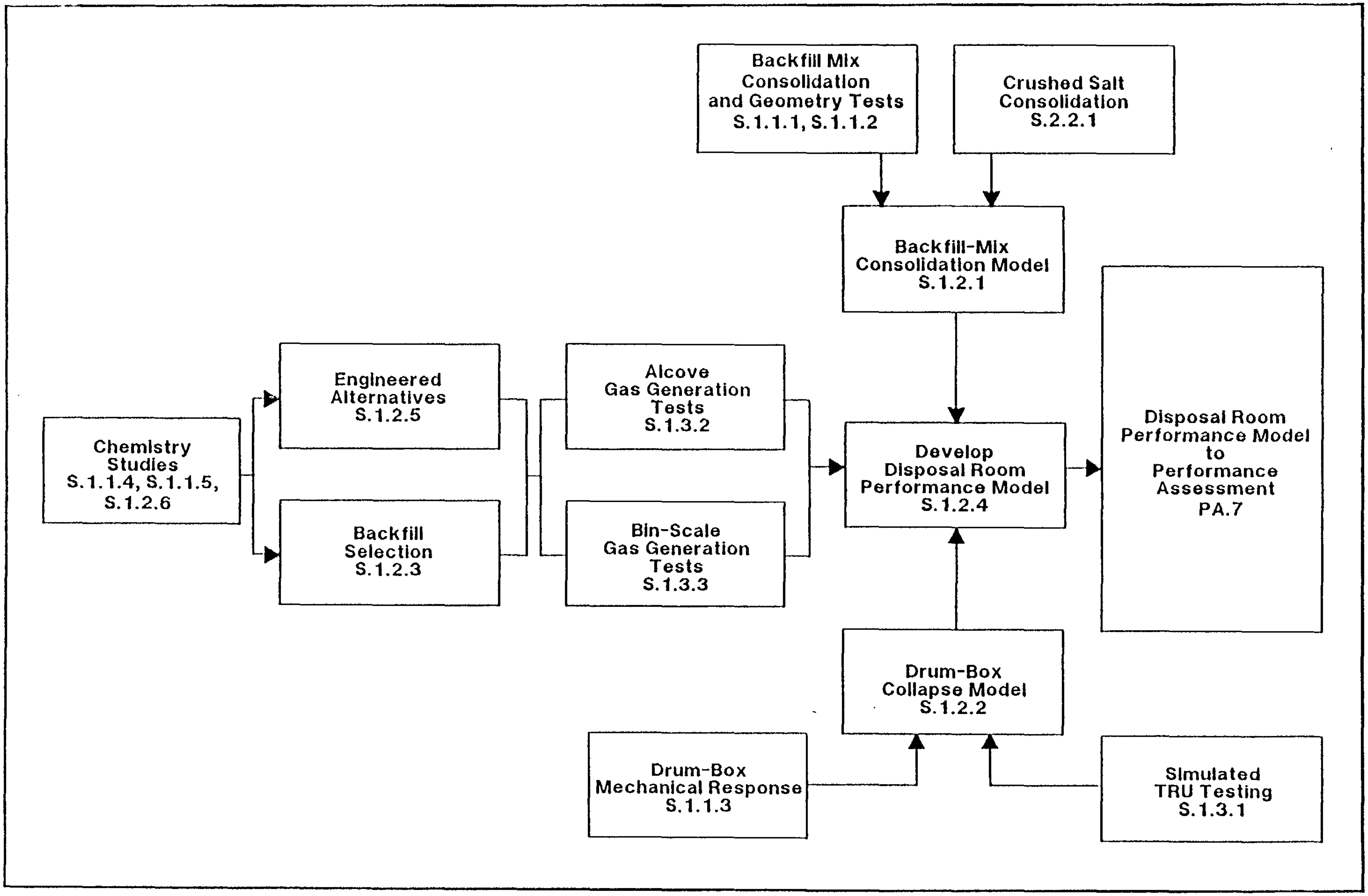


Figure 2-5. Relationship Among Disposal Room and Drift System Activities

Activity S.1.1.1
BACKFILL-MIX CREEP AND PERMEABILITY BEHAVIOR

1. Focus

Additives to the crushed salt backfill, such as bentonite (Stormont, 1988a), are being considered because of their expected ability to absorb radionuclides and brine that may leak toward the seals (Nowak, 1988). However, sorption of brine is accompanied by swelling which may exert pressures on the surrounding rock, thereby retarding room closure (Pusch, 1980). Knowledge of the permeability and sorptive properties of bentonite also allows an assessment of the potential migration of soluble radionuclides and hazardous waste constituents. Additives other than bentonite should be tested to control gases produced during waste decomposition. Data on additives and their effects on seal permeability and room closure must be determined so that a suitable backfill-consolidation model can be developed (Activity S.1.2.1), and backfills and seal mixes (Activity S.1.2.3) can be selected. As used here, backfill includes such possible additives as gas getters and inhibitors. More extensive modifications are considered in Activity S.1.2.5.

2. Methodology

Laboratory tests on creep consolidation rates of a salt-bentonite backfill mixture are under way, to be followed by permeability and swelling-pressure tests. Determinations of how much brine can be absorbed by the bentonite or other additives will be performed at various moisture levels. The effects of gas getters and inhibitors on the backfill consolidation will be determined. Experiments to determine the shear strength of design-basis and modified waste/backfill mixtures will be conducted.

3. Information Needs Addressed

Backfill (1.2.1.2)
Disposal Room Design (1.2.1.9)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Backfill (1.2.3.1)
Backfill (1.2.4.1)
Disturbed Rock Zone and Fluid-Flow Characterization (1.2.4.3)

Activity S.1.1.2
BACKFILL-MIX SELECTION TESTS

1. Focus

Most backfill tests in the laboratory are on uniform mixes with various additives (Activity S.1.1.1). However, an assessment will be made whether emplacement of different backfill mixes at various locations within the disposal rooms could better control brine inflow, movement of soluble compounds, or evolution of gases. For example, backfill-rich bentonite could be placed next to the walls, thereby acting as a barrier to brine inflow. This activity will provide data for model development (Activity S.1.2.1) and backfill-mix selection analysis (Activity S.1.2.3).

2. Methodology

Various configurations of backfill mixes will be investigated analytically and results will be correlated with laboratory tests before a backfill design is proposed. Brine or gases will be introduced from one boundary into various configurations of tailored backfill and the effectiveness of gas getters and brine sorption will be measured. Results will be evaluated and a backfill design or geometry proposed.

3. Information Needs Addressed

Backfill (1.2.1.2)
Gas (1.2.1.6)

Activity S.1.1.3
DRUM AND BOX MECHANICAL RESPONSE

1. Focus

Laboratory studies of the extent and rate of drum and box collapse as a function of applied load are necessary to predict (1) when backstress from the collapse process will begin to retard room closure (Activity S.1.2.4), (2) the final state of collapse of the containers in the absence of internal fluid pressurization; and (3) the relative times or rates of waste/backfill compaction and elimination of the disturbed rock zone.

Predictions of the time-dependent void and brine content of disposal rooms near their terminal consolidated state, as well as estimates of the time required for achieving this state, depend upon the final state of collapse of the containers. The contents of these containers are highly variable, ranging from low-density, easily compressible, combustible materials to dense, relatively incompressible metal objects. Initial void space within containers can be as much as 75 percent of the container volume (Clements and Kudera, 1985). The state of collapse of the CH drums and boxes will be determined by stresses developed during room closure (Huerta et al., 1983; VandeKraats, 1987). Confining pressures will not exceed the lithostatic pressure (2,200 psi), which may be insufficient to produce a final state of consolidation near theoretical solid density. This activity will provide data to the drum-box collapse model (Activity S.1.2.2).

2. Methodology

In experiments on drum and box collapse, load/volume measurements will be made during crushing of individual drums containing simulated CH-TRU waste to augment results already reported. First, the stiffening of the container during collapse as lithostatic stress levels are approached will be examined. The next experiments will crush scale models of assemblages of drums and boxes to determine how mechanical interactions between adjacent containers alter their collapse. Finally, crushed containers will be surrounded by wet backfill to determine rates of brine entry into the waste.

3. Information Needs Addressed

Container Response (1.2.1.3)
Systems Interaction (1.2.1.8)

Activity S.1.1.4
LABORATORY STUDIES OF REPOSITORY CHEMISTRY

1. Focus

Activities S.1.1.4 and S.1.1.5 investigate the overall geochemical behavior of the waste-emplacement rooms. As used here, "repository chemistry" describes the overall behavior with the exception of radionuclides, and "radionuclide chemistry" investigates the behavior of the radionuclides of interest, including potential formation of complexes with soluble VOCs.

Laboratory studies provide a unique opportunity to develop a mechanistic understanding of repository chemistry because they can (1) quantify the effects of significant processes under conditions that isolate each process from the complex effects of other processes, yet are nevertheless realistic; (2) determine the effects of variations in repository conditions on these processes. The laboratory studies are discussed in detail in Appendix A and by Brush (1989).

The repository chemistry laboratory studies have several objectives:

1. Quantify the production of hydrogen by anoxic corrosion of metals under various moisture conditions.

2. Quantify the effects of microbial degradation of the nonradioactive constituents of TRU waste on the gas and water budget of WIPP disposal rooms, the Eh and pH of any brine present, and the chemical behavior of radionuclides.

3. Determine the effects of radiolysis on the bioavailability of plastics and rubbers, and investigate the effects of waste compaction on gas generation by radiolysis.

4. Quantify the effectiveness and chemical effects of proposed backfill additives to remove gas or prevent its production.

5. If appropriate, investigate biodegradation of VOCs and material compatibility of soluble and volatile hazardous components with backfill components (e.g., bentonite) and cementitious seal components (e.g., salt-based grout).

2. Methodology

The methodology of each category of laboratory studies appears separately below.

<u>Laboratory studies of anoxic corrosion</u>

The objectives for these studies are to determine (1) anoxic corrosion rates for relevant iron and iron-based alloys in WIPP brines at 30°C, (2) whether anoxic corrosion of iron and iron-based alloys occurs using water vapor in equilibrium with free-standing brine and, if so, measure its rate, (3) whether anoxic corrosion of iron and iron-based alloys occurs using water absorbed by bentonite under partially saturated conditions, and if so, measure its rate, (4) whether anoxic corrosion of other metals (e.g., aluminum) in the WIPP inventory occurs and, if so, measure rates for these metals, and (5) whether elevated hydrogen fugacities will limit or prevent further anoxic corrosion under some conditions. The studies will be conducted at Pacific Northwest Laboratory.

These experiments will be designed to enhance preliminary studies of the anoxic corrosion of 1018 mild steel in synthetic brine (Braithwaite, 1978; Braithwaite and Larson, 1978; Molecke, 1979). The preliminary studies collected gases from the headspace above the brine and used gas chromatography to confirm the production of H_2 in deaerated runs.

Laboratory studies of microbial degradation of nonradioactive simulated waste

The objectives of these studies are to (1) determine whether potentially significant microbial processes occur under overtest conditions; (2) quantify the effects of those processes that actually occur on gas and water budgets of the repository under realistic, not overtest conditions; (3) determine whether the microorganisms responsible for significant processes are likely to survive for periods sufficiently long enough to affect the long-term performance of the repository, and (4) quantify the effects of any significant microbial processes on the chemical behavior of radionuclides in the waste. The studies are being conducted at Stanford University.

Presently, batch bioassay procedures utilizing substrates more biodegradable than cellulosic materials are being used to investigate denitrification, sulfate reduction, fermentation, and methanogenesis under conditions of brine saturation. To simulate the microorganisms that may be present in WIPP waste, microflora were obtained from laboratory air, surfaces, floors, human skin, and sewage sludge. Experiments will also be inoculated with halophilic microorganisms that could be present on dust particles transported by wind from salt lakes and soils proximal to the WIPP site. Abiotic and sterilized controls are run in all experiments.

For those microbial processes that actually occur, batch bioassays will be carried out with cellulosic materials under humid as well as inundated conditions to measure realistic gas production rates. Microbial activity is monitored by analyzing for organic acids, volatile acids, and the gases CH_4, CO_2, H_2, H_2S, and N_2, as appropriate. Organic acids are analyzed after separation by chromatography (Smith, 1987) and volatile acids by distillation (American Public Health Association, 1985). Gases (except H_2) are analyzed under anoxic conditions using gas-partitioning techniques (Tong et al., 1989). Hydrogen gas is measured by the mercuric-oxide technique of Smith (1987). If measurable amounts of gas are produced or consumed by microbial processes, rates will be calculated.

Short-term (a few months) and long-term (a few years) survival experiments will be conducted to assess whether microorganisms responsible for significant processes will survive for periods long enough to affect repository performance. These experiments are carried out by storing microorganisms in H_2O-saturated air and brine without cellulosic substrate. Survival testing for short-term experiments will be done by inoculating the stored microorganisms into favorable aqueous media. After yearly intervals, survival of microorganisms will be determined by adding acetate, cellulosic materials, glucose or lactate. Detection of microbial activity after inoculation or addition of these materials would imply that the microorganisms are still viable.

Studies of the effects of significant microbial processes on radionuclide chemistry will be initiated only if microbial processes occur at rates high enough to affect repository performance. If this investigation is necessary, studies will be carried out at Brookhaven National Laboratory. The potential effects of radionuclide complexing by organic constituents present in the waste, even in the absence of microbial activity, will be examined by Activity S.1.1.5.

Laboratory studies of radiolysis

The objectives for the radiolysis experiments are to (1) determine whether radiolysis of plastics and rubbers significantly enhances their biodegradability, and (2) quantify the radiolytic gas production rate for compacted waste under humid and brine-saturated conditions. The studies will be carried out at Argonne National Laboratory and Stanford University.

The first objective is under investigation. At this time, a detailed test plan is being drawn up to address the second objective. The former experiments are being carried out with brine collected from the WIPP underground workings using irradiated polyethylene and polyvinyl chloride as substrate. Abiotic and unirradiated controls are used in these studies.

Laboratory studies of proposed backfill additives

Laboratory studies of the backfill additives calcium carbonate, calcium oxide, copper sulfate, potassium hydroxide, and sodium hydroxide will be carried out to determine (1) whether these compounds remove gas or prevent its production effectively under conditions in which free brine is or is not present, and (2) quantify their effects on repository chemistry. The studies will be conducted at Sandia National Laboratories.

These studies are carried out with brines from the WIPP underground workings. Prior to the addition of a backfill additive to the brine, atmospheric CO_2 is removed from the test solution and all apparatus headspace by bubbling N_2 through the solution. Solutions or solids containing the backfill additives and mild steel are added to the brine and CO_2 is bubbled through the composite solution. Manometers measure the consumption of CO_2, and probes continuously monitor the pH and temperature of the composite solution. A pipette is inserted to sample the solution at various intervals for chemical analysis. Samples are shipped to United Nuclear Corporation (Grand Junction, CO) and analyzed for pH, specific gravity, total dissolved solids, boron, calcium, potassium, magnesium, sodium, alkalinity, bromine, chlorine, sulfate, and total inorganic carbon.

3. Information Needs Addressed

Source Term (1.2.1.1)
Gas (1.2.1.6)

Activity S.1.1.5
RADIONUCLIDE CHEMISTRY

1. Focus

Predictions of the chemical behavior of radionuclides in WIPP brines are necessary to determine the source term (i.e., the quantities of the important radionuclides in the WIPP inventory that will be mobilized for possible transport to the accessible environment) and the scenario-dependent rates at which these radionuclides will be mobilized. Because most plausible release scenarios involve advective or diffusive transport of radionuclides dissolved or suspended in aqueous fluids, the radionuclide source term ideally comprises (1) the product of the equilibrium or steady-state concentrations of radionuclides in brines that could enter WIPP disposal rooms after they are filled and sealed and the volumes of these brines, and (2) the rates at which these concentrations are attained and these volumes accumulate. Laboratory studies of radionuclide chemistry are discussed further in Appendix A and by Brush (1989).

It would be extremely difficult to predict the rates at which radionuclides dissolve or become suspended in WIPP brines, because these rates depend critically on the chemical and physical nature of the solid phases with which each radionuclide is associated. Because TRU waste is complex and difficult to characterize, it would probably be impossible to specify the nature of these phases accurately enough for meaningful kinetic studies. Furthermore, the solubilities of radionuclides in WIPP brines could well be so low that the rates at which solubility equilibria are attained would not affect repository performance even if they could be predicted. It will therefore be assumed that (1) the expected concentrations of radionuclides in brines are attained instantaneously, and (2) measured concentrations in leachate brines from bin-scale tests (Activity S.1.3.3.) represent these concentrations. In spite of this assumption, every reasonable effort will be made to verify that radionuclide concentrations are not increasing with time.

These studies of radionuclide chemistry will determine how processes such as the dissolution and precipitation of radionuclide-bearing solids, the sorption of radionuclides by solids such as bentonite or drum-corrosion products, and formation of metallo-organic ligand complexes distribute radionuclides between brines and solids in the repository, including colloidal-size particles. Transport studies will then determine the mobility of radionuclide-bearing brines and solids.

Radionuclide speciation under variable oxidation states affects the solubilities of radionuclide-bearing solids and the sorption of radionuclides by other solids such as bentonite and iron oxides. These processes in turn determine the concentrations of radionuclides in any available aqueous solutions. The most important radionuclides in TRU waste are isotopes of the actinide elements, especially plutonium (Pu), americium (Am), thorium (Th), and uranium (U). These elements can occur in two, three, or even four oxidation states under natural conditions, and the speciation, solubility, and sorption of an element can differ significantly from one oxidation state to another. These variations are difficult to study experimentally, because it is difficult to control the Eh of natural systems, especially at the low values (highly reducing conditions) that could be established by microbial activity in WIPP disposal rooms. Actinide chemistry is also sensitive to pH, which is difficult to measure in concentrated brines and may vary widely within the repository. In fact, both the Eh and pH of the repository could vary significantly with time and over distances of several centimeters at any given time because of the heterogeneity of TRU waste. It will thus be necessary to carry out experimental and/or modeling studies of actinide chemistry under a wide range of conditions, unless engineering modifications are sufficient to dominate or buffer repository chemistry.

2. Methodology

Laboratory studies of radionuclide chemistry

The objectives of these studies are to (1) identify and, if possible, quantify the organic and inorganic ligands in TRU waste; (2) obtain stability constants and solubility products for actinide complexes and solids, respectively, in brines; and (3) quantify, if possible, the effects of microbial activity on the concentrations of organic ligands and oxidation states of multivalent actinide elements.

The radionuclide studies will utilize estimates of the organic and inorganic liquids in CH TRU waste based on a detailed survey of waste generators and storage sites (Drez and James-Lipponer, 1989). Experiments to measure the stability constants of organic and inorganic complexes of americium, plutonium, thorium, and uranium (the principal actinides in CH TRU waste) are being conducted using a solvent extraction technique (Caceci and Choppin, 1983; Khalili et al., 1988). Highly saline solutions (5 to 8 M NaCl) are oxylate buffered at a pH of 6 (hydroxylamine buffer) or 8 (hydrazine buffer) and mixed with a benzene solution containing dibenzoylmethane and tributyl phosphate. By varying the concentration of oxylate in the aqueous phase and observing the distribution of americium between aqueous and organic solutions, apparent stability constants for americium(III)-oxylate and americium$(OH)^{+2}$ (americium hydroxide) have been determined (Caceci and Choppin, 1983). Similar studies will be designed to study plutonium complexing. After these techniques have been developed, plutonium, americium, thorium, and uranium solubility experiments will be conducted.

At this time, experiments which address the effect of microbial activity on the speciation and solubility of actinide complexes and solids are being planned. These experiments will be initiated only if microbial activity is shown to be a significant process in WIPP storage rooms.

3. Information Needs Addressed
Source Term (1.2.1.1)
Gas (1.2.1.6)

Activity S.1.2.1
BACKFILL-MIX CONSOLIDATION MODEL

1. Focus

A model predicting how nonsalt substances (e.g., granular gas getters, $CuSO_4$) may alter the rate of backfill consolidation will be developed so that the effect of these additives on room closure and the final consolidated state of the room can be estimated. A description of how swelling and swelling pressures in bentonite vary with moisture content is also needed for the analysis of seal performance.

Bentonite or some other water sorber may be added to crushed salt backfill within the disposal rooms where brine inflow is of concern (Activities S.1.1.1, S.1.1.2). Other additives may be introduced to scavenge gases resulting from waste and container degradation. Salt/bentonite mixtures could also be important seal components. Introduction of nonswelling, insoluble substances into the voids during consolidation is expected to have little effect upon predictions with the present constitutive model for moistened, crushed WIPP salt (Sjaardema and Krieg, 1987). However, brine sorption by bentonite causes swelling, which has the effect of increased back pressure or pore pressure within the voids, opposing consolidation. Activity S.1.2.4, the Disposal Room Performance Model, will depend in part on this activity.

2. Methodology

This effort will (1) convert the present constitutive model for consolidation of crushed salt into a model describing the consolidation of mixtures of salt and inert materials; and (2) develop a means for including either swelling or pore pressure resulting from the presence of bentonite in backfill consolidation and sealing predictions.

This activity will be initiated when the nature of the additives (gas getters and sorbents) is better defined.

3. Information Needs Addressed

Backfill (1.2.1.2)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Backfill (1.2.3.1)
Backfill (1.2.4.1)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)

Activity S.1.2.2
DRUM AND BOX COLLAPSE MODELS

1. Focus

An improved mathematical model of the collapse of CH-TRU waste containers is needed to predict the final void and brine content of the disposal rooms and the rates at which the final state will be obtained.

Because average pressures for compaction will not exceed lithostatic pressure (2,200 psi), they will not be sufficient to collapse the containers to near-theoretical solid density. The collapse model will estimate (1) when backstress from the container collapse process will begin to retard room closure, and (2) whether significant residual void volume will remain within the containers to allow relatively direct communication with an intrusion borehole or internal mixing of intruding brines. This activity directly supports development of the Disposal Room Performance Model (Activity S.1.2.4).

2. Methodology

Drum and box collapse modeling will involve two tasks. First, data from laboratory tests on individual drums and boxes (Activity S.1.1.3) will be used to construct as realistic a mathematical description of their collapse as possible. The variability of the container contents and their location within the disposal room (e.g., whether adjacent to the walls, or within the uppermost layer of containers next to the air gap) will also be considered. Second, the model will be generalized to estimate how the entire assemblage of drums within a room might respond collectively. The completed model will be combined with the backfill-mix consolidation model (Activity S.1.2.1).

3. Information Needs Addressed

Container Response (1.2.1.3)
Systems Interactions (1.2.1.8)
Disposal Room Design (1.2.1.9)

Activity S.1.2.3
BACKFILL-MIX SELECTION ANALYSIS

1. Focus

Backfill-mix selection and configuration analysis will determine the optimum backfill for the disposal rooms. The selection of backfill will be based on comparisons of coupled analyses that consider room closure and waste and backfill compaction. This represents the groundwork for a room performance model (Activity S.1.2.4). It differs from room performance analysis, however, because results from highly detailed, but normally independently functioning, models will be applied to candidate backfill configurations to arrive at a best design. For room performance assessment, one model, fully coupling all important variables in detail commensurate with importance, will be needed.

2. Methodology

Candidate backfills in engineered configurations will be analyzed to determine how brine inflow, waste container collapse, and other factors control the final state of consolidation of the room contents. These best estimate states of consolidation will be examined so that an optimal configuration for waste isolation can be identified.

A series of calculations will model as closely as possible the introduction of brine or gases from one boundary into various configurations of tailored backfill to determine the uniformity of brine (wicking action) and free gases throughout the configuration.

3. Information Needs Addressed

Backfill (1.2.1.2)
Backfill (1.2.3.1)
Backfill (1.2.4.1)

Activity S.1.2.4
DISPOSAL ROOM PERFORMANCE MODEL

1. Focus

A model that fully couples all the important variables of disposal room closure, in detail commensurate with importance, is needed to define the mechanical and physical state of the disposal room at the beginning of the various scenarios for the release of transuranic waste.

Several aspects of room performance must be specified at any given time: (1) how much room closure has occurred (Activities S.3.2.1 and S.3.2.2), (2) the state of consolidation of the backfill (Activity S.1.1.1), (3) how rigid the backfill is, (4) the permeability of various portions of the room, (5) the extent of dispersal of radioactive species from their containers (Activity S.1.1.5), (6) how much water and gas are present at what pressures (Activities S.3.2.4 and S.1.1.4), and (7) their distribution throughout the room.

The level of understanding in each area must be adequate to define room behavior as a function of time to a sufficient level of detail to support code simplification for performance assessment, if appropriate.

2. Methodology

Five steps are necessary in constructing a disposal room performance model: (1) identify critical components, such as the type of waste being stored, rate of room closure, and amount of inflowing brine that will determine the state of the room at any given time, (2) develop a means of mathematically describing these features that reproduces the essential features of the room without requiring excessive computation time, (3) develop and demonstrate a method of analysis, (4) incorporate into the model those features that reflect the backfill selection, as well as the final best estimates of room closure and brine inflow, and (5) complete and document a final version of the model. The ability to perform calculations that examine the combined effects of room closure, brine inflow, gas generation, and other important aspects of disposal room performance is the essence of steps (2) and (3). In model development, Darcy fluid flow analysis will be coupled into a finite-element structural mechanics computer code containing gas-generation source terms to determine room pressurization and resaturation. This analysis will be coordinated with the 2-Phase flow simulations of Activity S.3.2.5 to help assess the gas-generation source terms in coupled calculations of room closure. In addition, it will incorporate or generalize the results of more specialized modeling studies of waste and backfill (Activities S.1.1.1, S.1.1.2, S.1.2.1, S.1.1.3, and S.1.2.2).

3. Information Needs Addressed

Systems Interactions (1.2.1.8)
Disposal Room Design (1.2.1.9)

Activity S.1.2.5
ENGINEERED ALTERNATIVES

1. Focus

Modifications of the current reference disposal system design are being examined as a contingency, if performance assessment and experimental results have a high degree of uncertainty or are unsatisfactory. For planning, limited modifications, such as waste compaction and addition of gas getters to backfill, are considered here as part of the ongoing program, rather than as part of engineered alternatives. These activities are described elsewhere (e.g., Activities S.1.1.2, S.1.2.3). Activity S.1.2.5 addresses modeling of more extensive modifications.

2. Methodology

Alternatives options will be developed and evaluated for feasibility with respect to availability, state of the technology, cost, worker exposure, and regulatory concerns. An expert panel has initially screened the list of alternatives. Feasible options will be analyzed using a simple design analysis model to determine whether the modifications significantly improve the relative performance of the system. Integrating room-scale, shaft seal, and far-field submodels into a simple design analysis model will allow rapid calculations of a relative performance measure for the disposal system with respect to compliance with 40 CFR 191 and 40 CFR 268 (whichever is more restrictive). This design analysis model will be less complex than the large probabilistic models that will be used to demonstrate compliance with the EPA Standard. Sensitivity analyses using the design analysis model will define acceptable ranges for such parameters as initial waste void volume, initial backfill void volume, gas generation rates, and brine inflow rates.

Types of modifications that will be considered, in addition to those now being considered, include waste processing (e.g., vitrification, incineration), modifying the storage room or panel configuration, and modifying the repository design to reduce the probability of human intrusion. Specific alternatives that may be evaluated include waste compaction, incineration of the combustible components of the waste, use of a grout backfill to reduce void volume, replacing drums with rectangular containers, and the design of passive markers.

Engineered alternatives that seem feasible and effective will be modeled using the formal performance assessment process to quantify the improvement in disposal system performance. In parallel with the modeling effort, promising alternatives will be tested in bin-scale tests (Activity 5.1.3.3) and alcove tests (Activity 5.1.3.2) as appropriate.

3. Information Needs Addressed

Disposal Room Design (1.2.1.9)

Activity S.1.2.6
ADDITIONAL DEVELOPMENT OF EQ3/6

1. Focus

EQ3/6 is a set of computer codes and supporting data bases that calculate the speciation of solutes and the solubilities of minerals and other solids in aqueous solutions and predicts the chemical reactions between these solutions and solids, gases, or other solutions. This software package, developed at Lawrence Livermore National Laboratory (LLNL) for use by the commercial nuclear waste repository projects, can now model the chemical behavior of several key radionuclides in solutions with ionic strengths less than or equal to 1 M. Recently, LLNL added the Pitzer activity coefficient model to EQ3/6. The Pitzer model uses empirical ion interaction parameters to calculate activity coefficients for solutes. EQ3/6 then calculates solubilities and simulates chemical reactions. With the Pitzer option and currently available ion interaction parameters, EQ3/6 can now model the chemical behavior of various WIPP brines and evaporite minerals.

EQ3/6 cannot, however, model reactions between these brines and silicate minerals, because there are no ion interaction parameters available for Al and Si. Thus EQ3/6 cannot yet predict reactions between WIPP brines and any bentonite in the backfill, or between brines and the cements used to grout some of the drums and in seals. The University of California at San Diego is now developing ion interaction parameters for Al and Si.

Because ion interaction parameters are also unavailable for the important radionuclides in TRU waste, EQ3/6 cannot yet model the behavior of these radionuclides in brines. It would be difficult or impossible to obtain ion interaction parameters for the actinide elements from previously obtained experimental data, because few data were obtained at ionic strengths greater than or equal to 1 M. Furthermore, the Pitzer approach might not work at all for the actinides, because this model recognizes very few complex aqueous species explicitly, and the actinide elements form organic and inorganic complexes readily.

Without a reliable model, it will be impossible to predict the behavior of radionuclides in WIPP disposal rooms under conditions different from those investigated experimentally. It would prove extremely costly and time-consuming to measure radionuclide solubilities under all of the conditions that could occur in the repository.

A critical step in developing confidence in numerical models of radionuclide solubility and behavior will be the comparison and evaluation of laboratory studies (Activity S.1.1.5), brine leachate analyses from bin-scale tests (Activity S.1.3.3), and results of numerical modeling (Activity S.1.2.6).

2. Methodology

A model capable of predicting activity coefficients of radionuclides in brines will be developed and incorporated in the EQ3/6 software package developed by LLNL. This effort will (1) compile an internally consistent data set (ion sizes and hydration numbers) which, when used in the model, gives activity coefficients that agree with the experimental values for solution of simple composition; (2) evaluate these equations and data in solutions of complex composition; (3) incorporate the equations and data base into the EQ3/6 software package; (4) verify the computational capability of the code; and (5) document the code.

3. Information Needs Addressed

Source Term (1.2.1.1)
Gas (1.2.1.6)

Activity S.1.3.1
SIMULATED TRU TESTING (ROOMS T AND J)

1. Focus

In situ testing under both near reference and severe overtest conditions is in progress to examine drum deformation and backfill interactions with design-basis simulated containers and backfill. Other objectives are to measure backfill material behavior (emplacement, moisture, sorption, consolidation, and backfill applicability) and to provide data for the disposal room performance model (Activity S.1.2.4). These tests involve "near-reference" CH-TRU waste tests in Room T in a heated environment at 40°C (104°F) to accelerate results. Similar tests are also being conducted in Room J, in the presence of a large excess of brine, to accelerate aging and to simulate a "worst-case" repository environment.

2. Methodology

Tests in Room T involve the response of 240 simulated CH-TRU waste drums backfilled with either crushed salt or a tailored backfill consisting of 70 weight percent crushed salt and 30 weight percent bentonite. These drums are instrumented with remotely read pressure gages to measure the effect of closure on drum deformation. The tests have been in operation since March 1987 and will continue for a total of two to three years. Tests in Room J are similar, and have been in operation since June 1986. These experiments will provide preliminary information on rates and products of drum corrosion under brine-inundated, humid, and bentonite-wicking conditions (see Activity S.1.1.5).

3. Information Needs Addressed

Backfill (1.2.1.2)
Container Response (1.2.1.3)
Systems Interaction (1.2.1.8)
Backfill (1.2.3.1)

Activity S.1.3.2
ALCOVE GAS GENERATION TESTS

1. Focus

Data on the large-scale production, depletion, and composition of gases resulting from the in situ degradation of TRU wastes are needed to support performance assessment analyses and predictive modeling of long-term repository behavior (Activity S.1.2.4). Repository relevant and representative data on TRU waste degradation rates must be representative of time periods ranging from the operational phase emplacement to the longer term, postoperational phase. Data must be obtained in a controlled research mode, not simply as a monitoring function, to allow interpretation of multiple degradation mechanisms and impacts. Due to potential uncertainties introduced by extrapolating laboratory, small, or even bin-scale results to the full-scale repository configuration, it becomes necessary to validate gas generation models and the predicted impacts and consequences of gas generation by conducting room-scale tests with actual CH-TRU waste in the WIPP facility.

The full spectrum of data needed to address performance assessment and RCRA concerns can be obtained and satisfactorily resolved when data from the alcove tests are combined with the parallel laboratory (Activity S.1.1.5) and bin-scale tests (Activity S.1.3.3). The alcove, in situ data will be acquired from some of the first CH-TRU waste to be emplaced in the WIPP, under actual (as-received) and modified conditions.

2. Methodology

The CH-TRU waste to be tested in situ will be both as-received and specially prepared at the generator site, then shipped to the WIPP site. The waste must (room-by-room) include a representative mixture of waste types, waste loadings, and variations thereof. Waste types include high organic/newly generated (both standard and compacted from Rocky Flats Plant); low organic/newly generated (both standard and compacted from Rocky Flats Plant); processed, inorganic sludges; and high organic/old (stored) wastes.

The room-scale tests will involve six sealed, atmospheric controlled test rooms or alcoves. Five of the alcoves will contain test wastes; one will remain empty to serve as a gas baseline alcove. This testing arrangement allows the emplacement of lesser quantities of waste per room, so that more types of test conditions can be accommodated. A test alcove is tentatively defined as about one-third of the length of a full-sized waste room, with about 1,100 drums of test waste per alcove.

Gas data from the alcove tests will be acquired in two phases. Phase 1 will include two alcoves. The first will be empty and will provide gas baseline data; the second will contain as-received waste representative of the short-term, operational phase of the repository. Phase 2 will include four alcoves, specifically tailored to represent long-term, post-operational conditions in the the WIPP repository. Phase 2 tailoring will consist of alcove gas atmosphere control, special preparation of the waste, and brine injection.

Periodic gas samples from each of the test alcoves will be analyzed by gas chromatography-mass spectrometry for bulk composition and possible VOCs. Interpretations of this data will be input in to the performance assessment modeling program as soon as available and will also be used to guide and modify further testing. Waste mix compositions, types and quantities of waste drums and backfills, getters, degradation product contaminants, extent of brine moistening, atmosphere control (aerobic/anaerobic, pressures), and instrumentation and control hardware are described in detail in Appendix A. Full details will be available in a draft Test Plan for WIPP Room-Scale CH-TRU Tests, by the end of CY89.

3. Information Needs Addressed

Source Term (1.2.1.1)
Gas (1.2.1.6)
Disposal Room Design (1.2.1.9)

Activity S.1.3.3
BIN-SCALE GAS GENERATION TESTS

1. Focus

The gases generated by disposed TRU waste and their rates of generation as a function of time may significantly affect the assessment of radioactive releases from the repository by human intrusion. For the confident evaluation of the effect of the gases on potential release scenarios, data that define the appropriate waste degradation reactions and the amount and rates of gases generated are required. Several kinds of data on the potential in situ behavior of CH-TRU waste are needed: gas speciation, generation, and depletion rates as a function of time and several other waste condition parameters; source term definition of leached or mobilized chemical and radiochemical species; systems interactions and synergisms, etc. The impacts of radiolytic, bacterial, and chemical corrosion degradation mechanisms can be adequately analyzed and evaluated in these planned bin-scale tests using actual, radioactive TRU waste. The added degree of test control and the multiple test conditions to be used in these bin-scale tests allow the interpretation of obtained data to be simpler and more straightforward. Attainment of test data must not be simply a monitoring activity; it must be necessary for both analytical and predictive performance assessment modeling calculations and for validation of smaller scale laboratory data on simulated wastes. The full spectrum of required data can be obtained when these bin-scale tests are combined with the in situ room-scale tests (Activity S.1.3.2) and supporting laboratory tests (which use simulated wastes, Activity S.1.1.4). The bin-scale tests are discussed in more detail in Appendix A.

2. Methodology

These bin-scale tests are being designed to provide gas production and radiochemical source term data from actual, CH-TRU waste as a function of several representative types or classifications of waste; aerobic and anaerobic atmosphere conditions, representative of the operational phase and longer term, postoperational phase, respectively, of the repository; impacts of several types and quantities of brine inflow; impacts of waste interactions with salt, container metals, backfill, and gas getter materials - particularly on gas production and consumption; and waste gas production, which includes synergisms between the various degradation modes. The following test conditions must also be incorporated: conduct of the test must be controlled so that personnel safety is maintained; the scope and scale of the test must be adequately large to collect the quantities and types of data needed; the facility must not be contaminated during the course of the tests; facility operations and procedures must be realistically utilized.

The bin-scale test program is planned to take place in three phases. Phase 1 will incorporate test bins for which all components can now be defined. Backfill materials will be none, salt, or salt/bentonite. Approximately 48 waste-filled bins of different waste compositions and backfills, including replicates, will be included in Phase 1. Eight other, empty, Phase 1 test bins will be used for a pressure and gas-baseline reference during the test program. Phase 2 tests will incorporate another 68 waste-containing bins, with more moisture conditions, gas-getter materials, and supercompacted high-organic and low-organic wastes. Initiation of much of Phase 2 would depend on supporting laboratory data, particularly as to the composition of gas getters or other backfill material components, and the availability of supercompacted wastes. Phase 3 of the test program cannot be described in any detail at this time. Phase 3 test bins are required to accommodate potential test contingencies, specifically including any new engineering modifications to waste and backfill.

All test bins will have gas sampling ports, gas flushing ports (to control the initial bin atmosphere), pressure gage and control systems, and internal temperature monitoring instrumentation. Many of these bins will also be equipped with brine injection hardware (with liquids injected at the WIPP), liquid sampling ports, and possibly materials sampling ports. Periodic gas samples from each test bin will be analyzed by gas chromatography-mass spectrometry. Periodic liquid leachate samples from multiple bins will also be radiochemically analyzed for source-term (solution chemistry) data and evaluations.

Further details on the waste-mix compositions, exact types and quantities of wastes, backfill and getter materials, degradation product contaminants, bacterial inoculants, extent of brine moistening, atmosphere control (aerobic/anaerobic, pressures), hardware, and emplacement schedules are being prepared. These details will be available in a draft Test Plan for WIPP Bin-Scale CH-TRU Waste Tests by the end of CY89.

3. Information Needs Addressed

Source Term (1.2.1.1)
Gas (1.2.1.6)

2.7.2.2 Sealing System Activities

The sealing system characterization activities contain several laboratory, analytical, and in situ studies for the development of seal designs for WIPP shafts, panel drifts, and boreholes (Stormont, 1985; Stormont, 1988a; Tyler et al., 1988). These studies also develop techniques and models for assessing sealing system behavior and evaluating seal performance and provide data and analysis techniques for performance assessment of sealing systems.

The activity matrix, Table 2-4, for the sealing system identifies the applications. Laboratory studies provide data that are used in establishing material behavior, materials compatability (including RCRA concerns), and stability for seals and in evaluating the fluid-flow characteristics of the seal components. Modeling studies develop techniques for understanding and predicting interactions of seal components and the entire system in a host rock and for evaluating fluid-flow rates and paths through or around the sealing system. In situ testing provides data to evaluate performance of materials, establish interaction effects, and provide an understanding of the behavior of intact and disturbed rock surrounding the seals. Some of the tests can be conducted at smaller scales to reduce costs and increase the number of variables tested. The data are used to validate models to the extent possible and assess design concepts and ultimately to complete the WIPP performance assessment.

The sealing activities will evaluate (1) seal materials performance in small-scale seal tests, (2) seal systems performance in full sized seal tests, and (3) candidate seal materials and their performance in various rock environments. Figure 2-6 indicates the use of the data and information acquired from tests or theoretical studies. These data will be used in designing sealing systems and alternatives and to validate performance models of salt consolidation as a seal component. The product of this effort will be the recommended panel and shaft seal concepts and designs at decommissioning and input to the final performance assessment studies of transport through the sealing system.

The WIPP sealing system has undergone an extensive evaluation (Stormont, 1988a; Tyler et al., 1988). Data have been collected on seal system performance, formation permeabilities, and brine inflow. Data from these studies and the additional data that are being collected will provide a basis for addressing uncertainty about the WIPP seal system. The extensive models and data will require use of expert judgment to define the models and data used in the performance assessment.

Table 2-4. Applications of the Sealing System Investigations

Program-Area Activity	Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.2.1 Laboratory Studies:				
S.2.1.1 Geochemical Stability		Seal Material Properties		
S.2.1.2 Crushed Salt Consolidation	Waste/Backfill/Brine/ Room Interactions*	Seal Permeability		
S.2.1.3 Cementitious Materials Development	Seal Material Properties*	Seal Material Properties*		
S.2.2 Modeling Studies:				
S.2.2.1 Crushed Salt Consolidation Modeling	Waste/Backfill/Brine/ Room Interactions*	Seal Permeability		
S.2.2.2 Seal System Design Integration		Seal Performance		
S.2.3 In Situ Tests:				
S.2.3.1 Small-Scale Seal Performance Tests				
Vertical Concrete Seal		Concrete Seal Performance		
Horizontal Concrete Seal		Concrete Seal Performance		

*Denotes a secondary application

Table 2-4. Applications of the Sealing System Investigations (Concluded)

Program-Area Activity	Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
	Phenomena/Parameters Being Addressed			
Horizontally Emplaced Block-Type Seal		Salt and Salt/Bentonite Seal Performance		
Vertically Emplaced Block-Type Seal		Salt and Salt/Bentonite Seal Performance		
Composite Shaft Seal Simulation		Composite Seal Performance		
Anhydrite Seal Test		Anhydrite Seal Performance		
S.2.3.2 Large-Scale Seal Test		Seal Performance		
S.2.3.3 Borehole Plugging		Seal Material Properties		Borehole Plug Performance*

*Denotes a secondary application

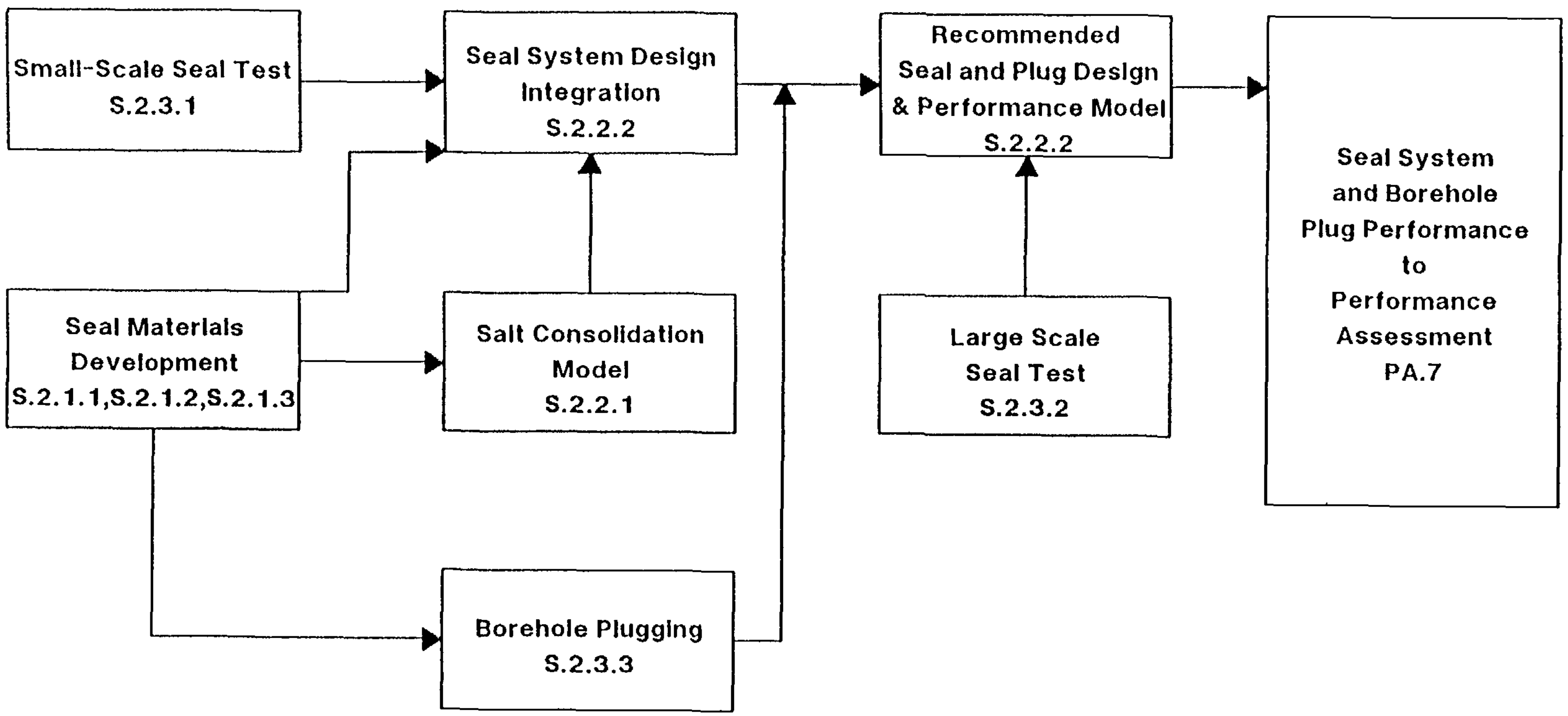


Figure 2-6. Relationship Among Sealing System Activities

Activity S.2.1.1
GEOCHEMICAL STABILITY

1. Focus

Laboratory studies of chemical reactions that could degrade seal material performance and the development of chemical models (Tyler et al., 1988) are necessary to provide reasonable assurance of adequate useful life for cementitious materials such as concrete and other component materials. Although reconsolidated salt has been chosen as the primary seal material, other proposed seal materials must function long enough to prevent brine and water inflow from inhibiting reconsolidation of the salt. Reactions of bentonite with WIPP brines, ground waters, cementitious materials, and hazardous waste components must be identified and incorporated into Activity S.2.2.2, Seal System Design Integration. Laboratory studies have shown that concrete-salt interactions are not likely to be deleterious over the short term.

2. Methodology

Laboratory work will include studies of chemical reactions and dissolution of cementitious materials in brines and ground waters. The aqueous phases are to have the compositions expected in the Salado Formation and overlying formations. Chemical reactions at the interface between concrete and anhydrite will also be studied. Emphasis will be on reactants other than dissolved halite; previous work indicates that halite does not significantly degrade cementitious materials. Evaluations will include, as necessary, the potential for chemical degradation of the seal materials as a result of interaction with the waste, including the hazardous waste components. Chemical models will then be developed to describe dissolution and rates of chemical reactions that may degrade seals. Seal materials will be chosen to maximize stability and meet required performance criteria.

3. Information Needs Addressed

Sealing System (1.2.2.2)
Sealing Criteria, Concepts, and Designs (1.2.2.4)
Sealing System (1.2.4.2)
Borehole Plugging-Material Behavior (1.3.4.1)

Activity S.2.1.2
CRUSHED SALT CONSOLIDATION

1. Focus

Because reconsolidated crushed salt is a key material in current seal designs (Activity S.2.2.2), accurate constitutive models, permeability relationships, and mechanistic understanding of crushed salt consolidation are essential. Consolidation is due to host rock creep. Shaft seal analyses have shown that crushed salt emplaced as a seal material will reconsolidate sufficiently to take over the sealing function from the concrete components within 100 years (Nowak and Stormont, 1987). These calculations showed that consolidation to 95 percent of intact-salt density should be complete well within 100 years. The constitutive relationships and permeabilities (10 nanodarcies at 95 percent consolidation) should be verified with further tests and expanded to include brine-saturated crushed salt.

2. Methodology

Laboratory studies have confirmed the rapid reconsolidation of moistened crushed WIPP salt under hydrostatic pressure. Consolidation rates of crushed salt under deviatoric (shear) loading will be determined next. Measurements will then be made on samples completely saturated with brine, to determine how fluid filled pores inhibit compaction. Finally, the extent that reconsolidation is accelerated by moisture will be measured in tests on samples which contain controlled quantities of added brine. The relationship between reconsolidation density and permeability will be determined in all test series. The results from this testing program will provide the information needed to couple consolidation modeling with brine inflow. Micromechanical models for consolidation of crushed salt (effect of particle size, etc.) will also be developed to support the constitutive models.

3. Information Needs Addressed

Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Sealing System (1.2.2.2)
Sealing Criteria, Concepts, and Designs (1.2.2.4)
Backfill (1.2.3.1)
Sealing System (1.2.4.2)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)

Activity S.2.1.3
CEMENTITIOUS MATERIALS DEVELOPMENT

1. Focus

The properties and performance of cementitious materials are extremely variable depending on their mixture, the application method, and the intended use. Present design concepts for sealing the WIPP repository include cementitious materials (Stormont, 1988a). These materials will function as concretes in the shafts and possibly in drifts, grouts in boreholes, and pressure grouting of potential shaft disturbed zones. Previous development has identified candidate saltwater concrete, saltwater grout, and freshwater grout (Gulich and Wakeley, 1988) for uses in shafts, drifts, and boreholes. Because of peripheral gypsum formation, typical concretes may not be stable in anhydrite, which is found in key shaft seal locations. Development must now focus on anhydrite bonding concretes, pressure grouts, and grouting techniques. Continued testing and characterization of previously developed WIPP specific cementitious materials should continue. This activity will ensure that the best possible cementitious materials are selected for sealing the WIPP repository (Activity S.2.2.2) and that an adequate or adequate data base of these properties exists for performance assessment.

2. Methodology

A series of tests will investigate workability, heat evolution, strength, stiffness, and permeability of possible anhydrite-bonding concrete mixtures. Once a mixture is identified as a candidate, field tests will be conducted (Activity S.2.3.1). Existing pressure grout formulations will be similarly screened, laboratory tested, and field tested. Standard laboratory tests will supplement these field tests as well as field tests supporting previously identified candidate mixtures.

3. Information Needs Addressed

Sealing System (1.2.2.2)
Closure (1.2.2.3)
Sealing Criteria, Concepts, and Designs (1.2.2.4)
Sealing System (1.2.4.2)
Borehole Plugging Material Behavior (1.3.4.1)

Activity S.2.2.1
CRUSHED SALT CONSOLIDATION MODELING

1. Focus

Reconsolidated, crushed WIPP salt is the key seal material in current seal-system concepts (Activity S.2.2.2). Numerical model calculations will be used to predict the density and permeability of emplaced crushed salt as a function of time after emplacement.

In response to reconsolidation by creep closure, crushed salt can reach permeabilities comparable to that of intact host rock salt within 100 years (Nowak and Stormont, 1987). Tailored seal shapes may be needed to facilitate rapid and uniform reconsolidation of emplaced, crushed salt seal material. Numerical calculations of consolidation are needed to guide the design of seal shapes. New information on the deviatoric behavior of WIPP crushed salt is a key input to this effort. Therefore, updated calculations are needed as deviatoric behavior is quantified by laboratory tests.

Numerical calculations should be repeated as constitutive relationships for crushed salt are updated from the laboratory test results and the development of a mechanistic model. These calculations will provide the most accurate estimates of seal system permeability and offer the best guidance for seal system design and seal excavation shapes.

2. Methodology

The numerical, crushed salt consolidation model will be updated to include the latest data from laboratory tests (Activities S.2.1.1 and S.2.1.2). New information on deviatoric behavior will be incorporated. The consolidation behavior of brine-saturated crushed salt may also be included. Consolidation calculations will be repeated for cases that are likely to be changed significantly by an updated model. The time required to reach a low permeability is important for evaluating seal performance.

Calculations will be made of crushed salt consolidation in proposed seal excavation shapes to guide the choice of seal shapes for rapid consolidation to high density and low effective permeability.

3. Information Needs Addressed

Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Sealing System (1.2.2.2)
Backfill (1.2.3.1)
Backfill (1.2.4.1)
Sealing System (1.2.4.2)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)

Activity S.2.2.2
SEAL SYSTEM DESIGN INTEGRATION

1. Focus

A large number of diverse activities, including modeling and numerical analyses of complex seal systems, must be integrated to complete conceptual seal designs for the WIPP facility.

The structural and flow responses of the seals and the surrounding host rock must be modeled and analyzed to evaluate seal system performance. Coupled processes of brine inflow, consolidation, creep closure, disturbed zone formation, and stress concentration will be included. These analyses will require that outputs from many testing and model development activities (Activities S.2.1.1, S.2.1.2, S.2.1.3, S.2.2.1, S.2.3.1, S.2.3.2, and S.2.3.3) be available for the numerical analyses.

2. Methodology

Models and codes to calculate and analyze the structural and flow performance of seal components will be developed and will include the response of the surrounding host rock, including disturbed zone formation. Numerical analyses of structural and flow processes to evaluate seals and to guide the design of tests or experiments will include coupled processes, such as brine inflow during crushed salt consolidation.

A conceptual design for WIPP plugging and sealing systems will be prepared by an architect/engineering contractor after evaluating seal designs by analyzing the structural and fluid-flow processes that occur. The design will be sufficiently detailed to provide a basis for preparing a WIPP construction design.

3. Information Needs Addressed

Sealing System (1.2.2.2)
Sealing Criteria, Concepts, and Designs (1.2.2.4)
Sealing System (1.2.4.2)
Closure (1.2.4.4)
Sealing Criteria, Concepts, and Designs (1.2.4.5)
Borehole Plugging Material Behavior (1.3.4.1)
Borehole Plug Interaction (1.3.4.2)
Borehole Plugging Criteria, Concepts, and Designs (1.3.4.3)

Activity S.2.3.1
SMALL-SCALE SEAL PERFORMANCE TESTS

1. Focus

Measurement of thermal/structural/fluid flow performance of the shafts, drifts, and panels sealing system will provide data for seal design (Activity S.2.2.2) and long-term performance assessment. Stresses and strains induced in the seal and rock will result from hydration of concrete, and from the interactions of salt creep and the seal material. The stresses and strains are important in assessing the stability of the sealing system and in evaluating the structural/fluid-flow relationships. Both gas and brine permeabilities are important in evaluating the efficacy of the sealing system. Sealing system permeability measurements are needed to provide data on flow rates through the system, identify dominant flow paths, and determine the difference between gas and brine seal system permeability.

To provide the data, tests are required on (1) vertical concrete seals, (2) vertically emplaced salt and bentonite block seals (Stormont, 1988b), (3) a composite shaft seal (Stormont, 1988b), (4) a horizontal concrete seal (Stormont and Howard, 1986), (5) a horizontal seal of salt blocks (Stormont, 1988b), and (6) a seal compatible with anhydrite layers (Stormont, 1984).

2. Methodology

Testing has been initiated to support many of the data needs. Boreholes ranging in size up to 38 in. (96 cm) in diameter, both horizontally and vertically, have been instrumented and are collecting data with simulated plugs installed. Gas and brine fluid-flow measurements will determine in situ fluid flow performance of a simulated seal. Rooms will need to be excavated to initiate composite shaft seal tests and to support anhydrite seal tests.

Horizontal concrete seals tests were initiated in 1986. Structural data will continue to be collected and compared with the predicted model response. The concrete/salt rock model, which incorporates elastic as well as inelastic behavior of both concrete and salt, will be used to develop the design and stability of facility level panel and drift seals (Labreche and Van Sambeek, 1988). Fluid-flow/permeability measurements for gas and brine will be continued and will include gas with tracers and brine as the working fluids.

Horizontally-emplaced block seal tests were initiated in the spring of 1986. Structural data will continue to be collected and will be compared with the response predicted using the laboratory-developed, salt consolidation constitutive model. This model will be used for the design of panel and drift seals. There are four instrumented seals: two salt-block seals and two salt/bentonite block seals. The remaining four uninstrumented seals (two salt and two salt/bentonite) are for permeability or fluid-flow testing. Instrumentation in the four seals will measure deformations and pressures. The present understanding of the consolidation process implies that crushed salt provides little resistance to closure until it is very dense; measurements of deformation of the seal and the pressure buildup at the seal/rock interface should verify or refute this laboratory determination. The magnitudes of the pressures and deformations will aid in assessing the stability of the block-type seals and, when coupled with the fluid-flow measurements, in evaluating the structural/fluid flow interaction. For example, laboratory measurements suggest that the potential for flow should dramatically decrease when the porosity of crushed salt decreases to a range of 5 to 10 percent.

Fluid-flow testing is ongoing. Nitrogen gas is being used as the working fluid for some of the fluid-flow or permeability tests, because gas measurements are faster, easier, and less costly. Gas tests will be less destructive to the sealing systems than brine, particularly to salt-block seals before they have consolidated to relatively low porosities. Brine is being used to test salt/bentonite seals soon after emplacement to assess brine uptake, the physical stability of the salt/bentonite system, swelling pressures, "steady-state" permeability, and erodibility.

Vertical concrete seals testing was initiated in 1985. Structural/thermal data will continue to be collected and compared with the predicted model response (Stormont, 1987). The concrete/salt rock model, which incorporates elastic and inelastic behavior of concrete and salt, will be used to develop the design and stability of concrete shaft seals, which is a key component in the present seal design concept for the Salado Formation (Stormont, 1988a; Van Sambeek and Stormont, 1987).

Emplacement of vertically emplaced salt-block seal tests was initiated in November 1987. One uninstrumented seal has been emplaced, one empty borehole has been instrumented with closure gages, and two instrumented seals have been installed. Four more seals will be installed and structural data will continue to be collected and compared with the response predicted using the laboratory developed, salt-consolidation constitutive model. This model is for the design of shaft seals. There will eventually be eight boreholes, of which seven will contain seals. Currently, one borehole contains closure instrumentation only, one emplaced seal is uninstrumented, and the other six emplacements will be instrumented. Three seals are 100 percent salt blocks, four seals are all bentonite. Half of the seals are instrumented to measure deformations and pressures. The remaining half are intended for permeability or fluid-flow testing. The current salt consolidation model implies that crushed salt provides little resistance to closure until it becomes very dense (i.e., until seal material properties approach that of the surrounding rock mass). The measurements of seal deformation and pressure buildup at the seal/rock interface and within the seal itself should assess and improve the current salt consolidation modeling. Quantitative measurements of pressure and deformation will aid (1) in assessing the stability of the salt block and bentonite/salt block seals and (2) in evaluating the structural/reconsolidation/fluid flow interaction when coupled with the fluid-flow measurements. For example, laboratory measurements suggest that the potential for flow should dramatically decrease when the porosity of crushed salt decreases to a range of 5 to 10 percent.

Fluid-flow testing will be conducted similarly to the horizontally emplaced block-type seal. Brine will be used to test the seals one to two years after seal emplacement to assess reconsolidation, stability of the sealing system, brine uptake, swelling pressures, erodibility, and the like.

Six composite seals will be emplaced in six 48-ft (15-m) deep, 3.3-ft (1-m) diameter boreholes at the WIPP facility. These simulated shaft seals will consist of approximately 3.3-ft (1-m) thick layers of expansive salt saturated concrete and salt or sand mixed with bentonite clay on either side of a central core of quarried salt blocks. Three of the sealing systems will be instrumented with thermocouples, pressure cells, and displacement gages. The other three seals will be used solely for fluid-flow testing. Short duration tracer gas testing and long duration brine testing is planned. The emplacements may include shapes other than simple cylindrical shapes for the individual seal components.

Six seals will provide in situ data on the efficacy of various candidate seal materials and techniques for sealing anhydrite layers in the shafts and at the disposal horizon. These seals will be emplaced in six 3.3-ft (1-m) diameter boreholes that pass through the 3.3-ft (1-m) thick Marker Bed 139 anhydrite layer. One test will monitor the mechanical performance of an anhydrite-bonding concrete (ABC) by means of thermocouples, pressure cells, and strain and displacement gages. The remaining five seals are for fluid-flow testing: (1) ABC plug, (2) ABC plug with adjacent rock grouting, (3) bentonite-based seal confined by ABC, (4) bentonite-based seal confined by crushed salt blocks, and (5) bentonite-based seal confined by ABC with adjacent rock grouting. Short duration, tracer gas testing will be followed by long-term, brine flow testing.

3. Information Needs Addressed

- Sealing System (1.2.2.2)
- Closure (1.2.2.3)
- Sealing Criteria, Concepts, and Designs (1.2.2.4)
- Sealing System (1.2.4.2)
- Closure (1.2.4.4)
- Borehole Plugging Material Behavior (1.3.4.1)
- Borehole Plug Interaction (1.3.4.2)
- Borehole Plugging Criteria, Concepts, and Designs (1.3.4.3)

Activity S.2.3.2
LARGE-SCALE SEAL TEST

1. Focus

The expected performance of shaft and waste panel seals will be based primarily upon laboratory and field data, small-scale in situ tests, and modeling. Small-scale tests do not fully simulate the development of the disturbed zone around larger excavations. Therefore, a large-scale test is needed to evaluate sealing concepts for the shaft and panel seals (Activity S.2.2.2). Previous seal evaluations indicate that the seal/rock interface and rock adjacent to the seals are the most likely hydrologic flow paths. Additionally, the excavation, seal emplacement, and rock creep may result in stresses or deformations that will affect both seal and rock performance.

Current conceptual designs call for seals to be composed of quarried salt, salt/bentonite mixtures, and pressed salt blocks (Stormont, 1988a). This design should provide a seal comparable to the intact formation in less than 100 years. This design provides for removal of heavily fractured rock at strategic locations to minimize the potential for seal bypass. The multiple component design also provides some redundancy. An alternative design includes concrete, which could be used in the panel seal design for several reasons: (1) for confinement of salt- or bentonite-based seal components, (2) to reverse formation disturbance by causing stress build-up, (3) as a short-term flow barrier, or (4) as an additional redundant component.

2. Methodology

Tests will be designed to examine both salt and concrete seals for both shafts and panels. It is intended that the test will be designed in a drift mined to approximately 10 x 10 x 50 ft (3 x 3 x 15 m). Both salt-block and concrete plugs will be installed and open intervals pressurized to determine the effective seal permeabilities as a function of time as salt creep acts upon the system. Therefore, with both tests, a proven optional design can be used if the primary design does not perform as expected.

3. Information Needs Addressed

Sealing System (1.2.2.2)
Closure (1.2.2.3)
Sealing Criteria, Concepts, and Designs (1.2.2.4)
Sealing System (1.2.4.2)
Sealing Criteria, Concepts, and Designs (1.2.4.5)

Activity S.2.3.3
BOREHOLE PLUGGING

1. Focus

The principle fluid-bearing zones above the repository are the Culebra and Magenta Members of the Rustler Formation. To prevent dissolution, these fluid-bearing zones must be sealed off from the disposal horizon and from the halites of the Salado and Castile Formations. Plugging boreholes will also enhance confidence that the radiologic consequences have been bounded by further slowing or preventing flow into the boreholes. Sealing concepts should address both the Salado and Castile Formations and the formations above and below them. Grouts and cementitious materials, appropriate to the geology and geochemistry of each formation, should be evaluated for their ability to restrict fluid flow and maintain structural stability. Borehole plugging supports Activity S.2.2.2.

2. Methodology

An evaluation of the borehole-plug-material interaction and the interactions of different plug compositions with each other will be conducted. The borehole plug criteria, concepts, and designs will be performed in parallel to the extent possible. Finally, an evaluation of borehole plugging performance will be prepared.

3. Information Needs Addressed

Borehole Plugging Material Behavior (1.3.4.1)
Borehole Plug Interaction (1.3.4.2)
Borehole Plugging Criteria, Concepts, and Designs (1.3.4.3)

2.7.2.3 Salado Formation Structural and Fluid-Flow Behavior Activities

This section describes activities related to the structural- and fluid-flow behavior of the Salado Formation (Table 2-5). The activities support, first, the development of the general structural-response predictive technology, including validation of models against in situ data, and second, the evaluation of fluid-flow characteristics (Figures 2-7 and 2-8) of the Salado Formation in the shaft and in the salt surrounding the disposal room.

The predictive technology for understanding the structural behavior consists of three important elements: (1) constitutive model development (Activity S.3.2.1), (2) the numerical or code framework (Activity S.3.2.2), and (3) material properties (Activities S.3.1.1-S.3.1.5). Laboratory material property studies reduce the uncertainty in the properties data base, and hence in performance assessment calculations, for investigating the effect of moisture on the creep rate as it applies to closure. This also relates to an understanding of the role of healing under pressure of salt around seal systems. In addition, a possible source of the discrepancy noted earlier (Morgan et al., 1985; Munson et al., 1986) between measured and predicted in situ response may be the stress generalization (Munson and Fossum, 1986). As a result, an intensive laboratory effort to define the proper stress generalization is being undertaken. Analysis will guide the successful development of the prediction technology by determining the underlying physics and material response of salt as observed in laboratory and in situ. The predictive technology will ultimately be validated to the extent possible by comparing numerical predictions with the results of extensive, large-scale, in situ tests. Gathering suitable, in situ data for validation is a major task (Activity S.3.3.1). Proper Quality Assurance-certified, authenticated data are the result of strictly controlled data reduction to produce an archived data base, which is made available to the scientific and engineering community through data reports (e.g., the Room H report, Munson et al., 1987).

The ability to predict the closure of and brine inflow to rooms and shafts is a fundamental requirement of the WIPP Project and forms the basis for several other programs. The closure and fluid inflow rates and conditions are the principal input to specifying the physical and mechanical condition of the room contents, as required by the system studies of drum condition and backfill recompaction. The closure rates, and hence the rate of stress buildup on the seals, determines how the seals retain their integrity with time and how salt surrounding the seal returns to the condition required. As a result, nearly all design and performance calculations specifying the state of the seal systems and the formation or specifying the damage and rehealing of salt around the seal systems are based on the structural response predictive technology. Ultimately, structural and fluid inflow calculations for the disposal rooms will be called upon to predict long-term closure and reconsolidation times.

Some activities will evaluate the fluid flow characteristics and behavior of (1) brine and gas inflow and permeability in the far-field domain, (2) brine and gas flow within the near-field or disturbed rock zone, and (3) geophysical properties of the rock formations in the shaft and underground, with emphasis on the disturbed rock zone. The flow diagram (Figure 2-8) indicates the manner in which the fluid flow activities support the development of models that will be used in the WIPP performance assessment.

Table 2-5. Applications of the Salado Formation Structural and Fluid-Flow Behavior Investigations

Program-Area Activity	Phenomena/Parameters Being Addressed			
	Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.3.1 Laboratory Studies:				
S.3.1.1 Stress Generalization; Verification of the Creep Flow Surface	Waste/Backfill/Brine Room Interactions*	Seal/Rock Interaction	Room Closure	
S.3.1.2 Transient Strain Limit Determination	Waste/Backfill/Brine/ Room Interactions*	Seal/Rock Interaction	Room Closure	
S.3.1.3 Pressure Effect on Fracture Rehealing	Waste/Backfill/Brine/ Room Interactions*	Seal/Rock Interaction	Room Closure, Fracture Healing	
S.3.1.4 Moisture Effect on Creep Rate	Waste/Backfill/Brine/ Room Interactions*	Seal/Rock Interaction	Room Closure	
S.3.1.5 Stress, Strain/ Brine Transport	Salt Permeability*		Salt Permeability	
S.3.2 Modeling Studies:				
S.3.2.1 Constitutive Model Development	Waste/Backfill/Brine/ Room Interactions*	Seal/Rock Interaction	Room Closure	
S.3.2.2 Numerical Code Development	Waste/Backfill/Brine/ Room Interactions*	Seal/Rock Interaction	Room Closure	

*Denotes a secondary application

Table 2-5. Applications of the Salado Formation Structural and Fluid-Flow Behavior Investigations (Continued)

Program-Area Activity		Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.3.2.3	Code Verification and Validation	Waste/Backfill/Brine/ Room Interactions*	Seal/Rock Interaction*	Room Closure	
S.3.2.4	Brine Inflow Model	Brine Inflow*		Brine Inflow	
S.3.2.5	3-D Mechanistic Hydrological Transport Model of Facility	Brine Inflow*		Brine Inflow	Ground-Water Flow, Radionuclide Transport*
S.3.2.6	Integrated Mechanical Model, Disturbed Rock Zone (DRZ) and Excavation Effects	Brine Inflow*	Seal Permeability, Seal Performance*	DRZ Properties, DRZ Behavior	
S.3.3	In Situ Tests:				
S.3.3.1	Air Intake Shaft Performance		Shaft Closure, Seal/Rock Interaction*	Shaft Closure	
S.3.3.2	Intermediate-Scale Borehole Test (Room C1)	Room Closure*	Seal/Rock Interaction*	Room Closure	
S.3.3.3	Panel Structural-Response Test	Panel Response*		Panel Response	
S.3.3.4	Gas Flow/Permeability	Salt Permeability	Seal Performance, DRZ Properties*	Salt Permeability, DRZ Properties*	
S.3.3.5	Near-Field Flow Characterization	Salt Permeability*	Seal Performance, DRZ Properties*	Salt Permeability, DRZ Properties	

*Denotes a secondary application

Table 2-5. Applications of the Salado Formation Structural and Fluid-Flow Behavior Investigations (Concluded)

Program-Area Activity	Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.3.3.6 Brine Inflow Scale and Stratum Effects	Brine Inflow	Brine Inflow*	Brine Inflow	
S.3.3.7 Pore Pressure for Brine Inflow			Brine Inflow	
S.3.3.8 Brine Inflow to Excavated Rooms	Brine Inflow	Brine Inflow*	Brine Inflow	
S.3.3.9 Brine Permeability Testing of the Disposal Horizon	Brine Inflow, Salt Permeability	DRZ Properties, Salt Permeability*	Salt Permeability, Brine Inflow	
S.3.3.10 Air Intake Shaft Brine Permeability Testing		DRZ Properties, Salt Permeability, Seal Performance, Fracture Healing*	DRZ Properties, Salt Permeability	DRZ Properties, Lower Rustler Hydrologic Properties, Ground-Water Flow, Radionuclide Transport*
S.3.3.11 Shaft Geophysics		Seal Permeability, Salt Permeability, DRZ Properties, Seal Performance*	DRZ Properties, Fracture Healing	
S.3.3.12 Underground Geophysics	DRZ Properties, Salt Permeability*	Seal Permeability, Salt Permeability, DRZ Properties, Seal Performance*	DRZ Properties, Fracture Healing	
S.3.3.13 Brine Sampling and Evaluation Program	Brine Inflow, Brine Distribution*		Brine Inflow, Brine Distribution	

*Denotes a secondary application

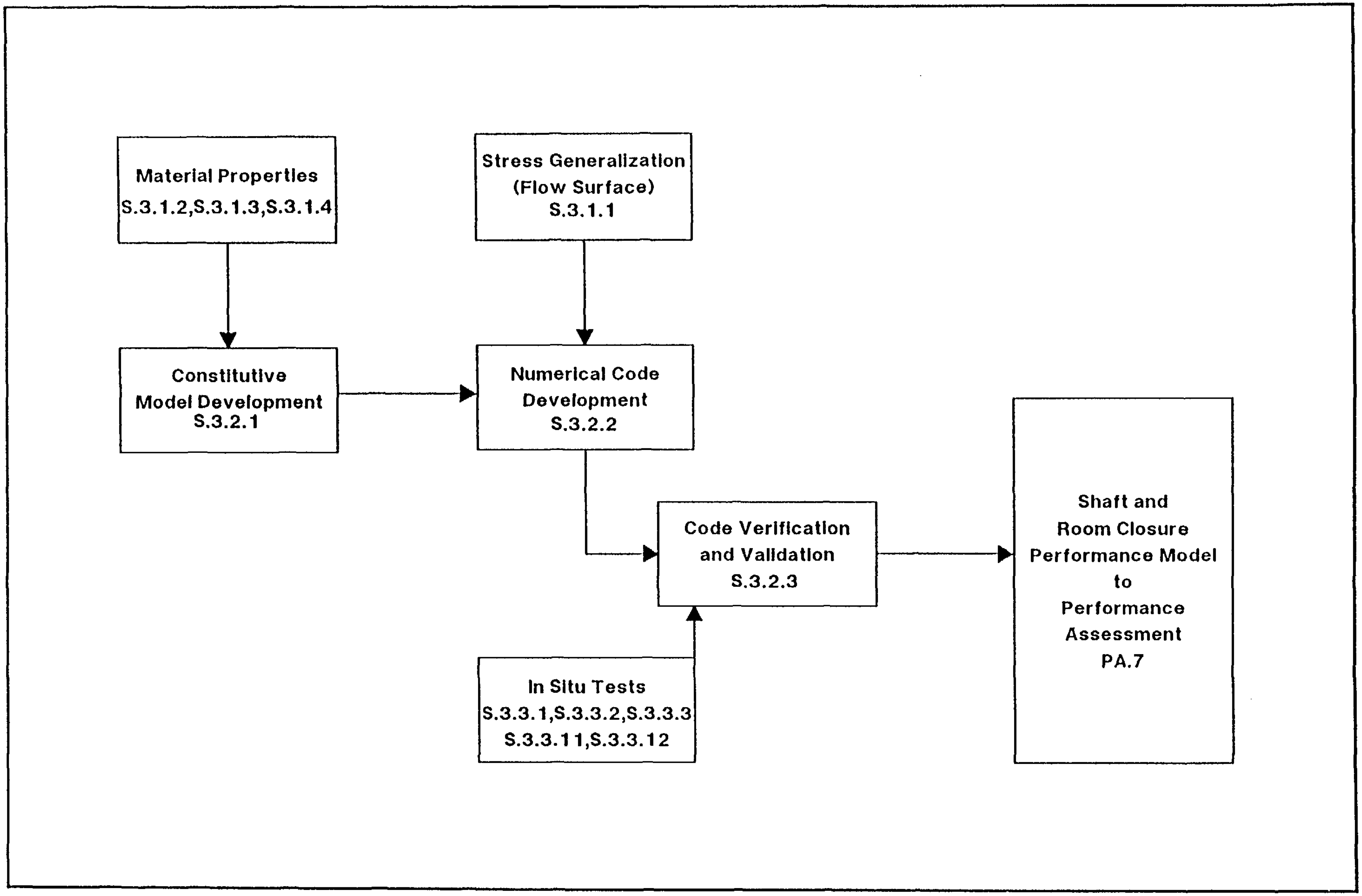


Figure 2-7. Relationship Among Salado Formation Structural Behavior Activities

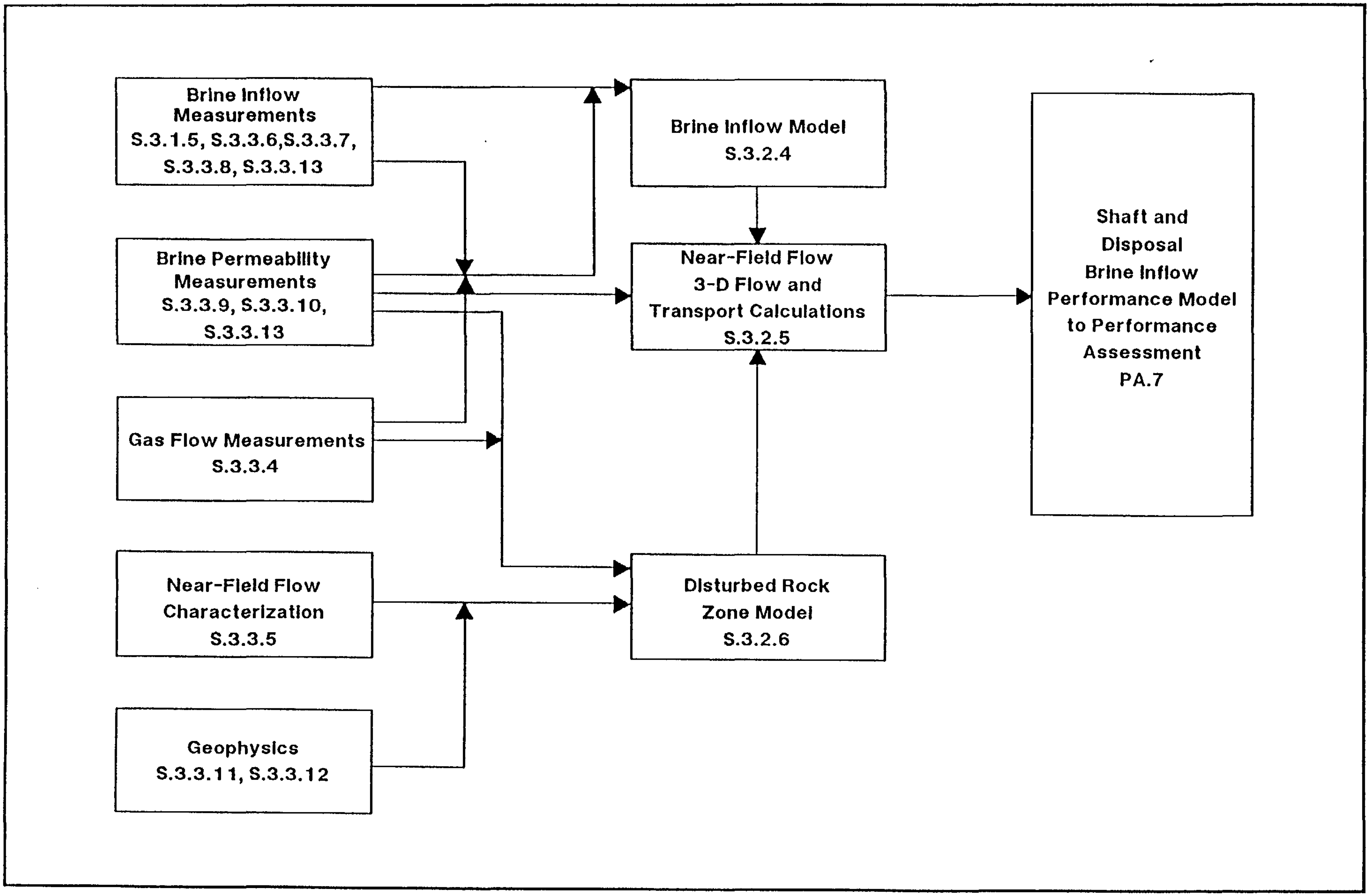


Figure 2-8. Relationship Among Salado Formation Fluid-Flow Behavior Activities

Activity S.3.1.1
STRESS GENERALIZATION; VERIFICATION OF THE CREEP FLOW SURFACE

1. Focus

Most compliance arguments strongly depend upon the time at which the waste is encapsulated. As a result, uncertainties in the numerical calculations of the time for room or shaft closure must be reduced. These tests focus on identifying which of two probable stress generalizations (von Mises or Tresca) should be used in calculating creep rate and, therefore, room closure. Significant differences in creep rate exist depending on which stress generalization more accurately reflects the conditions at WIPP. The results of this activity will be incorporated into the numerical prediction codes for salt creep (Activity S.3.2.2).

2. Methodology

The three-dimensional creep flow surface for pure salt will be determined by (1) testing large thin-walled cylinders of salt under pure shear, and (2) testing of thick-walled cylinders under controlled, known stress gradients. The proper form of the stress generalization can then be developed and incorporated into numerical solution techniques. Finally, verification of the form of the stress generalization for the range of WIPP salt and evaluation of the influence of the intermediate principal stress on salt creep will be completed.

3. Information Needs Addressed

Container Response (1.2.1.3)	Closure (1.2.2.3)
Closure (1.2.1.4)	Closure (1.2.3.3)
Disposal Room Design (1.2.1.9)	Closure (1.2.4.4)

Activity S.3.1.2
TRANSIENT STRAIN LIMIT DETERMINATION

1. Focus

Transient-strain parameters of the constitutive models (Activity S.3.2.1) are important in resolving the discrepancy between calculated and measured room closure (Munson and Dawson, 1982).

This parameter appears to control the magnitude of the calculated strain, somewhat independently of the strain rate. While, theoretically, the evaluation of the transient strain limit (a measure of the total transient strain) should be apparent from the conventional creep data, it has actually proven difficult to quantify. The difficulty arises from the nature of the conventional creep test and from the prestrain condition of the salt being tested. Standard creep tests measure the strain at constant stress as a function of time; as a result, strain that occurs within the sample during loading before the value of constant stress has been reached is "zeroed out." Therefore, this loading strain never appears in the material parameters or calculations within the constitutive model that is determined from the laboratory creep data, and thus, any calculation of actual room deformation excludes an important component of transient strain (Munson and Fossum, 1986). Loading strain will be included in the material parameter data base and incorporated into the constitutive models. Additional testing will be performed on the ERDA-9 deep borehole salt, which forms the principal data base for the constitutive modeling, to evaluate the loading strains and transient creep behavior of this material.

Laboratory measurements of creep strains also exclude strains accumulated in the specimen before it reaches the laboratory for testing. Although testing of natural salt is similar to metals testing, it differs in that the initial condition of the salt is not well controlled and rarely defined. This problem becomes significant for salt, because natural salt specimens may have a strain history that differs according to how and when they were cored from the parent salt body. This history may change the appearance and magnitude of the transient strain measured in laboratory creep tests. These small prestrains are especially important in predicting underground room closure, because the strains are comparable to those experienced in the salt surrounding the rooms. This prestrain influences the transient strains observed in the two major WIPP creep data bases, the ERDA-9 deep borehole data base, and the WIPP-D facility horizon data base. As a result, observed transient creep strains in these two data bases differ because the histories differ. Specifically, the WIPP-D facility specimens are thought to contain more prestrain than the ERDA-9 borehole specimens. It is essential to quantify the effects of these prestrain histories on transient creep and then to correct the data bases back to the undisturbed state of the in situ salt.

2. Methodology

This activity consists of three major tasks:

a. Creep testing of core from the ERDA-9 deep borehole to establish loading strains and any other testing strains not in the current data base. This testing program contains only three ERDA-9 borehole specimens from the same material layer as the WIPP-D specimens. Thus, the transient strain data can be compared directly (with the exception of differences in prestrain history) between identical material. The specimens used for the previous or existing ERDA-9 creep tests all came from a horizon well above the facility horizon.

b. Continued determination of the free dislocation density for ERDA-9 and WIPP-D salt to establish quantitative comparisons. A more detailed study will be made of WIPP-D salt to obtain the dislocation density as a function of distance from the room opening for comparison with the known displacement values measured in salt surrounding the room. This study will quantify the dislocation density with the measured displacements.

c. An annealing study of WIPP-D specimens to intentionally reduce the free-dislocation density will be continued, first to determine the annealing conditions needed to achieve the desired densities, and second to generate the WIPP-D data base by creep-testing annealed specimens at conditions comparable to those used in previous tests of unannealed specimens.

Minor routine testing will be used to decrease uncertainty in the creep parameters, as necessary.

3. Information Needs Addressed

Container Response (1.2.1.3)	Closure (1.2.2.3)
Closure (1.2.1.4)	Closure (1.2.3.3)
Disposal Room Design (2.1.1.9)	Closure (1.2.4.4)

Activity S.3.1.3
PRESSURE EFFECT ON FRACTURE REHEALING

1. Focus

The integrity of seals emplaced in the repository includes the salt around the seal, because of increased permeability of the host rock caused by the excavation. Laboratory study of the amount of fracturing developed by strain under confining conditions and the fracture behavior dependence on time and pressure will quantify fracture rehealing. This activity also supports constitutive model development (Activity S.3.2.1). Laboratory evidence from nonspecific tests suggests that existing fractures will heal under the pressure state as it developed in the salt around the seal (Sutherland and Cave, 1978; Costin and Wawersik, 1980). However, confirming this will require experiments specifically designed to quantify the healing process.

2. Methodology

An ultrasonic technique for identifying fracturing in salt laboratory specimens will be calibrated for the WIPP salt. Then the ability to quantify the generation of fractures as a function of creep or strain will be possible. The time-dependent relationships between pressure and the decrease of fractures will be established to obtain healing kinetics.

3. Information Needs Addressed

Closure (1.2.1.4)
Disturbed Rock Zone (1.2.1.7)
Disposal Room Design (1.2.1.9)
Closure (1.2.2.3)
Disturbed Rock Zone (1.2.3.2)
Closure (1.2.3.3)
Closure (1.2.4.4)

Activity S.3.1.4
MOISTURE EFFECT ON CREEP RATE

1. Focus

The potential influence of brine within the repository or in the salt surrounding the repository as it affects room closure has been studied (Hunche, 1984; Borns, 1987). There are two schools of thought on the effect of the brine moisture: (1) moisture increases the creep rate of salt, or (2) moisture has no effect on the creep rate. No specific mechanism or model consistent with both extremes has been constructed. Most interpretations suggest that the phenomenon is related to changes in the bulk creep property of the salt even though, theoretically, it seems unlikely. If it is hypothesized that the location or influence of moisture accelerates the growth of fractures that result from dilatant deformation, it appears most of the previous unreconcilable results could be explained. This experiment would test the hypothesis and support the constitutive model development (Activity S.3.2.1).

2. Methodology

Experimental equipment and test procedures for moisture testing and specimen preparation must be developed. Then, the extent of fractures as a function of creep strain and confining pressures will be determined. Also a determination of the response of the creep rate to moisture conditions will be made. To complete the process, the reversibility of the effect of moisture on salt creep will be assessed.

3. Information Needs Addressed

Container Response (1.2.1.3)	Closure (1.2.2.3)
Closure (1.2.1.4)	Closure (1.2.3.3)
Disposal Room Design (1.2.1.9)	Closure (1.2.4.4)

Activity S.3.1.5
STRESS, STRAIN/BRINE TRANSPORT

1. Focus

Host rock permeability is critical for predicting brine inflow to the rooms and shafts using the existing brine transport model (Activities S.3.2.4 and S.3.2.5). The current model (McTigue and Nowak, 1987) treats the host rock as a poroelastic medium; however, the halite exhibits plastic behavior. Plastic effects could cause changes in the salt permeability that are not accounted for in the elastic model. Such mechanisms are likely to be significant only during early times after excavation and then to decrease in importance. However, strain induced brine flow changes should be included in the model to quantify their potential for long-term contribution to inflow.

2. Methodology

This activity will be initiated if the data gathered by Activities S.3.2.4 through S.3.3.10 demonstrate the importance of creep-closure-initated brine inflow or if data are insufficient to demonstrate its importance.

The first step will be to derive the relationship between strain resulting from creep closure of the excavations and the effective permeability of the host rock. A mechanistic understanding of damage, dilatation, or other restructuring that occurs with the creep during excavation closure could then be developed. Strain induced changes in the host rock must be related to brine inflow models. Finally, computer models of quarried salt blocks must be derived to facilitate predictions of seal component behavior and interaction with the host rock.

3. Information Needs Addressed

Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone (1.2.1.7)
Disposal Room Design (1.2.1.9)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Disturbed Rock Zone (1.2.3.2)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)

Activity S.3.2.1
CONSTITUTIVE MODEL DEVELOPMENT

1. Focus

Two distinct efforts are involved in the creep constitutive modeling: (1) reassessment or reevaluation of parameters and incorporation of secondary effect functions and (2) development of a fracture model. A consistent set of parameters will be developed for each of the relevant constitutive models of salt creep. Those secondary functions (now required) will be added to the constitutive models to replace constants currently in the models. The fracture model development effort will center on a fracture mechanism map related to the actual observation of fracture modes in the repository horizon. These functions will be formulated and incorporated into the appropriate numerical codes (Activity S.3.2.2).

2. Methodology

All relevant laboratory data from the ERDA-9 borehole and WIPP-D (Room D) data bases will be assembled. The data bases will be evaluated in a consistent manner for the specific constitutive creep models relevant for use in performance assessment activities. The necessary secondary functions will be formulated and the data base parameters evaluated to construct a fracture mechanism map. The appropriate fracture models from the mechanism map and the observed underground fracture modes will be formulated. The fracture parameters for the models will be evaluated for existing laboratory and underground data.

3. Information Needs Addressed

Container Response (1.2.1.3)	Closure (1.2.2.3)
Closure (1.2.1.4)	Disturbed Rock Zone (1.2.3.2)
Disturbed Rock Zone (1.2.1.7)	Closure (1.2.3.3)
Disposal Room Design (1.2.1.9)	Closure (1.2.4.4)

Activity S.3.2.2
NUMERICAL CODE DEVELOPMENT

1. Focus

This activity consists of five major development efforts. Three of the efforts are two-dimensional code development for (1) incorporating alternative stress generalizations into the codes, (2) incorporating the effects of a layered media into the codes, and (3) modifying codes to permit progressive fracturing and to incorporate fracture models. The remaining two efforts involve three-dimensional code development and will (4) improve the material models and stratigraphy descriptions permitted in the codes and (5) improve the input generation and output graphics of the codes.

2. Methodology

The Tresca stress generalization criterion will be developed and installed in a large strain/deformation code. The proper formulation for the clay seam and bedded material representation will be investigated. A "true" fracture physics for progressive fracture development during the calculation including stress redistribution will be developed. The codes will incorporate the appropriate fracture models for the observed modes of underground fractures. Methods and equipment for input and output for the three-dimensional code solutions will be improved also. This activity will be coordinated with the development of the integrated mechanical model of the disturbed rock zone (Activity 3.2.6) and with the assessment of the potential for fracture generation or propagation associated with waste-generated gas (Activity S.3.2.5).

3. Information Needs Addressed

Container Response (1.2.1.3)
Closure (1.2.1.4)
Disturbed Rock Zone (1.2.1.7)
Disposal Room Design (1.2.1.9)
Closure (1.2.2.3)
Disturbed Rock Zone (1.2.3.2)
Closure (1.2.3.3)
Closure (1.2.4.4)
Salado Formation (1.3.2.1)

Activity S.3.2.3
CODE VERIFICATION AND VALIDATION

1. Focus

There must be a continuous effort to assure that numerical codes are, in fact, producing physically correct calculations independent of the structural model involved or the details of the constitutive equations. Code confirmation, verification, and validation will continue as each new generation of code becomes available (Activity S.3.2.2) and as significant advances are made in constitutive modeling. Among the new two-dimensional codes that must be advanced through this system are the large strain/deformation codes with more sophisticated constitutive models and alternative stress generalizations.

The benchmarking process for two-dimensional codes is relatively well defined. The increasing use of new three-dimensional codes means that a method for code verification is a critical element in the development of a three-dimensional calculational capability, however. Many thermal/structural interaction problems related to WIPP configurations are three-dimensional, and a two-dimensional analysis will not produce acceptable results. These problems must be analyzed with codes capable of handling exact three-dimensional configurations. JAC-3D is a recently developed code using the conjugate gradient iterative technique for the quasistatic analysis of three-dimensional, nonlinear solids. Although this code has been evaluated, and in some sense benchmarked, throughout its development, it has not been benchmarked specifically to the WIPP class of nonlinear problems, a step that must be accomplished to establish the necessary degree of confidence for WIPP calculations. The final stage in developing code prediction techniques is the formal validation process of showing acceptable prediction of in situ results for a range of conditions, configurations, and uncertainties in input parameters. The initial validation must establish code readiness in time for performance-assessment calculations for EPA compliance, and the formal process must be completed and documented prior to the acceptance of the WIPP facility as a repository. All relevant two- and three-dimensional codes used for these calculations must be validated, if possible, and made available for use by the Project.

2. Methodology

Typically codes are evaluated against simple analytic solutions, which leaves the bigger and more significant problem of verification as a major activity. Verification is not straightforward, because of the nonlinearity of the problems being solved. As a consequence, no analytic solutions are available against which the codes can be verified. The approach taken is to "benchmark" several codes against the same well-defined boundary value problems; comparable code solutions indicate that the codes are solving the physics correctly, even though the benchmark exercise does not guarantee that the calculations produce the correct answer (Matalucci et al., 1981; Morgan et al., 1981; Munson and Morgan, 1986). Since the correct answer cannot be assured by verification exercises alone, the codes require validation against actual in situ data, whenever possible, to assure correctness of the solutions.

The two major tasks within this activity are verification by benchmarking and validation by comparing calculations to in situ results. Continued verification of new two-dimensional codes through established benchmarking methods will produce acceptable codes for performance assessment and operational safety questions. Because so few three-dimensional codes are available, a somewhat new approach will be developed for verifying three-dimensional codes. To this end, JAC-3D will be benchmarked initially by using it three-dimensionally to compute solutions to simple two-dimensional boundary value or creep problems that have been previously analyzed with two-dimensional codes. Any discrepancies will be resolved. The next step in benchmarking will consist of three-dimensionally solving a more realistic, two-dimensional configuration, such as the configurations of the Benchmark II and Parallel Calculation exercises. When all discrepancies of these nonlinear problems have been resolved, the final step will be to benchmark the JAC-3D code to another three-dimensional code in a direct code-to-code comparison for a complex, but controlled, problem.

Validation will be the culmination of the analysis of the in situ data. It will summarize the current status of the codes, uncertainties, and accuracy of the prediction of the in situ results. The task will establish the formal documentation of the validation process against the in situ data for the most appropriate two- and three-dimensional codes.

3. Information Needs Addressed

Closure (1.2.1.4)
Disposal Room Design (1.2.1.9)
Closure (1.2.2.3)
Closure (1.2.3.3)
Closure (1.2.4.4)
Salado Formation (1.3.2.1)

Activity S.3.2.4
BRINE INFLOW MODEL

1. Focus

Any scale-up of brine inflow test data to large excavations and extrapolation of those data to long times for performance assessment requires a model (Activity S.3.2.5). A brine-inflow model, based on mechanistic understanding, will be developed from the results of in situ brine-inflow, pore-pressure, flow-characterization, and permeability studies (Nowak and McTigue, 1987) (Activities S.3.3.6, S.3.3.8, S.3.3.13). The brine-inflow rate from the host rock is a key input to models for the consolidation of emplaced crushed salt in seal structures and for waste room response to creep closure.

2. Methodology

Numerical techniques will be developed to expand the existing brine-inflow model to include spatially and temporarily variable permeability. Permeability will be allowed to vary as a function of stress and/or strain in the host rock. Heterogeneities in the host rock, strain induced changes in host rock flow characteristics, and multiple brine flow mechanisms will be assessed as potential contributors to the total flow. The potential impact of waste-generated gas on brine inflow will be assessed in coordination with the two-phase simulations in Activity S.3.2.5.

Mechanistic submodels (based on both in situ and laboratory test data designed to test and elucidate brine-inflow mechanisms) will be developed to provide the fundamental relationships in the numerical model. Simplified geometries may be used to maximize the efficiency of this effort, and emphasis will be given to modeling and matching the experimental results.

Numerical models will be modified to include new mechanisms that may contribute significantly to brine inflow. The mechanistic, experimental, and numerical modeling efforts must be closely coupled for that reason.

3. Information Needs Addressed

Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Salado Formation (1.3.2.1)

Activity S.3.2.5
THREE-DIMENSIONAL MECHANISTIC HYDROLOGICAL TRANSPORT MODEL OF FACILITY

1. Focus

Detailed models describing mechanisms of flow and radionuclide transport will provide a framework for assimilating field and laboratory data into a characterization of hydrologic conditions at and near the WIPP facility.

2. Methodology

A documented data base from past and ongoing field testing programs will be developed. The data base will continue to evolve from ongoing near- and far-field permeability testing in the facility and shafts (e.g., Activities S.3.3.4, S.3.3.5, S.3.3.6, S.3.3.9, S.3.3.10).

The models will analyze flow and transport mechanisms near the WIPP facility and will provide a predictive capability for simulating flow and transport under a variety of physical conditions.

The models will include the underground facility, shafts, and surrounding rock mass (including both the disturbed zone and intact rock). Modeling will emphasize (1) flow and transport mechanisms at and near the shafts and facility horizon under both undisturbed and disturbed (high-pressure-breach) conditions; (2) the impact of stratigraphic heterogeneities and excavation-related stresses on flow and transport; (3) the hydrologic relationships between the Salado Formation and adjacent units; and (4) the impact of waste-generated gas on fluid flow and transport. The upper portion of this model (Rustler Formation to land surface) will provide a three-dimensional interface for climate related modeling in Activity S.4.2.1. The approach taken in determining the controlling transport mechanisms will be an outgrowth of that taken by Reeves et al. (1987) in considering the Culebra Dolomite Member under undisturbed conditions and transport within the Culebra under brine-reservoir-breach conditions (Activity S.4.2.2). This method evaluates parameter sensitivity and importance based on the development of dimensionless type curves for solute breakthrough under single-porosity and dual-porosity (fracture) conditions. two-Phase fluid-flow modeling that incorporates the impact of waste-generated gas will be coordinated with the coupled room closure and fluid flow simulations in Activity S.1.2.4 to assess the impact of room closure on room repressurization. If the experimental assessment of gas generation rates (Activities S.1.1.4, S.1.1.5, S.1.3.2, and S.1.3.3) and preliminary two-phase simulations suggest that gas pressures will be high enough to generate or propagate fractures, then gas-induced fracture modeling will be carried out in coordination with Activities S.3.2.2 and S.3.2.6.

SWIFT II will be used for numerical modeling of single-phase flow and transport studies because of: (1) its capabilities in handling both flow and transport in dual-porosity and variable fluid density environments, (2) its ongoing use in Culebra flow and transport studies (Activities S.4.2.1, S.4.2.2), and (3) its complete public documentation and Quality Assurance status (e.g., Reeves et al., 1986a; 1986b). SWIFT II will be modified for coupling with an appropriate mechanical deformation code, if preliminary analyses show this capability to be important for simulating flow in the immediate vicinity of the excavations.

ECLIPSS 100 will be used initially for numerical modeling of 2-phase (brine and gas) flow because of (1) its well tested multiphase capability; (2) its dual-porosity capabilities for simulating flow in the fractured rock in the disturbed rock zone; and (3) its borehole simulation capabilities for simulation of human intrusion scenarios.

3. Information Needs Addressed

Disturbed Rock Zone (1.2.1.7)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Disturbed Rock Zone (1.2.3.2)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Salado Formation (1.3.2.1)
Rustler/Salado Formation (1.3.2.3)
Rustler/Dewey Lake Red Beds (1.3.2.6)
Boreholes Plugging Criteria, Concepts, and Designs (1.3.4.3)

Activity S.3.2.6
INTEGRATED MECHANICAL MODEL, DISTURBED ROCK ZONE, AND EXCAVATION EFFECTS

1. Focus

The design and emplacement of drift, panel, and shaft seals require a description of the disturbed rock zone, which forms in response to excavation. Evolution of the disturbed rock zone through time and in response to emplacement of and closure around the seals will be predicted.

The primary objective of this activity is to compile and update the geologic or conceptual model of the disturbed rock zone. To the extent possible, however, the applicability of available numerical modeling techniques to the mechanical behavior of the disturbed rock zone will also be evaluated, in conjunction with Activity S.3.2.5.

2. Methodology

This task will integrate visual observations during mining and geophysical data around the underground openings at the WIPP facility (Activities S.3.3.11 and S.3.3.12) into a conceptual mechanical model of the disturbed rock zone. This model will be an outgrowth of the preliminary conceptual model (Borns and Stormont, 1988) and will incorporate the results of ongoing studies, such as the seismic tomography studies (Skokan et al., 1988). Some predictive capability for modeling fracture development will be acquired. This and other activities, such as Activities S.3.3.1 - S.3.3.13, will provide a data base that ensures consistency of the three-dimensional mechanistic flow and transport model (Activity S.3.2.5).

3. Information Needs Addressed

Closure (1.2.1.4)
Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone (1.2.1.7)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Closure (1.2.2.3)
Sealing Criteria, Concepts, and Designs (1.2.2.4)
Disturbed Rock Zone (1.2.3.2)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Closure (1.2.4.4)
Salado Formation (1.3.2.1)

Activity S.3.3.1
AIR INTAKE SHAFT PERFORMANCE

1. Focus

Detailed shaft closure data will form the basis for validating shaft-closure models to determine the time for reconsolidation of shaft fill material and stress configurations around seals (Activity S.3.2.3). The microfracture/permeability correlation will be used for evaluations of effective seal conditions. The structural investigation of the shaft will determine its closure rates as a function of depth. Additional tests will correlate the ultrasonic signal attenuation with strain and microfracturing-induced permeability increases in the shaft wall.

2. Methodology

The complete closure history of the shaft wall can be determined from early time data onward as a function of time and location within the shaft. Instrumentation consisting of extensometers, thermocouples, and closure measurement points will be installed at five elevations in the shaft. Several sets of paired holes were drilled on opposite walls of the shaft immediately after that section of the shaft was bored to provide early-time data on shaft closure. The time dependent changes within the host rock as a function of distance into the salt will be determined by ultrasonic signals. The changes in ultrasonic velocities in the shaft wall may then be correlated with strain displacement and permeability. Finally, the effects of seasonal temperature variations on the salt will be measured and analyzed in conjunction with the structural behavior of the shaft.

3. Information Needs Addressed

Closure (1.2.4.4)
Sealing Criteria, Concepts, and
Designs (1.2.4.5)
Borehole-Plug Interaction (1.3.4.2)

Activity S.3.3.2
INTERMEDIATE SCALE BOREHOLE TEST (ROOM C1)

1. Focus

   The test will resolve whether a scale effect can be observed in salt to better resolve the difference between laboratory and field data used in predicting room closure rates. Although salt lacks the joint sets that account for scale effects in hard rock, it does contain interbeds that could account for a scale effect.

2. Methodology

   A test will be initiated to drill and instrument a pilot hole and other boreholes through the pillar in Room C1. The pilot hole will be overcored with a 36-in. (91-cm) diameter hole while monitoring the three-dimensional array of extensometers and closure gages surrounding it. Data from the instrumentation will be acquired for two to three years to evaluate the scale effect and then correlated with data from other structural tests and calculations.

3. Information Needs Addressed

   Closure (1.2.4.4)
   Sealing Criteria, Concepts, and
   Designs (1.2.4.5)
   Borehole-Plug Interaction (1.3.4.2)

Activity S.3.3.3
PANEL STRUCTURAL-RESPONSE TESTS

1. Focus

The closure rates of the disposal rooms and the overall structural response of a seven-room panel has been based on data from the Site and Preliminary Design Validation rooms and access drifts (Bechtel, 1986a; 1986b). Other information about creep response has resulted from in situ tests supporting other experiments (Tyler et al., 1988). Data from a full-scale seven room panel would provide increased confidence and reduced uncertainty (Activity S.3.2.3) in the long-term structural behavior of a panel.

2. Methodology

A full-sized seven-room panel was excavated (Panel 1) and geomechanical gages immediately installed in the pillars and roof to measure creep rates and convergence over time. Remotely read instruments are connected to a data acquisition system. Both remotely and manually-read instruments will contribute to a five-year data base. The data will be evaluated and analyzed, then correlated with other data to reduce uncertainties in the structural response of the panel.

3. Information Needs Addressed

Closure (1.2.4.4)
Sealing Criteria, Concepts, and
  Designs (1.2.4.5)
Borehole Plug Interaction (1.3.4.2)

Activity S.3.3.4
GAS FLOW/PERMEABILITY

1. Focus

Gas flow measurements help to define the extent of the disturbed rock zone surrounding a mined opening (Activity S.3.2.6). The measurements indicate relative permeability of the host rock to gas as a function of distance from the opening. The data are important to seal design and evaluation because flow through the total seal system depends in part on the rock in which the seals are placed. The gas flow tests may also provide information for evaluating the buildup and dissipation of natural and waste-generated gas.

2. Methodology

Portions of boreholes will be isolated using a packer system. Nitrogen will be injected in the test interval, then either a flow rate at constant pressure or pressure decay will be measured. The data will be used to estimate gas dissipation rates, determine gas permeability variations, and better understand the creation and nature of the disturbed rock zones. These data will be input to models of permeability strain and permeability stress coupling.

3. Information Needs Addressed

Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Sealing Criteria, Concepts, and Designs (1.2.2.4)

Activity S.3.3.5
NEAR-FIELD FLOW CHARACTERIZATION

1. Focus

Near-field flow characterization is part of the effort to better understand the ability of the host rock to transmit fluids (Activity S.3.2.6). This is important to brine inflow estimates, seal design, gas dissipation, and overall facility performance. Fundamental assumptions used when calculating permeability from single hole tests will be assessed based on characterization of near-field flow. Interpretations of previous single hole injected flow and inflow measurements have not considered instantaneous, near-field, excavation-induced changes. These changes may dominate flow characteristics of the rock surrounding the drift.

2. Methodology

A test will be initiated in which dye is injected into boreholes that will then be overcored. The dye in the fractures will delineate flow paths in the near field. Another test will be an array containing pressurized gas and brine, which will be monitored during the drilling of an adjacent large-diameter hole. The brine-hole response will provide data to be directly related to the poroelastic model used to predict brine inflow. The gas-hole response will be compared with the brine response and previous gas-flow measurements. These data will assist in estimating the amount and significance of deformation concurrent with excavation.

3. Information Needs Addressed

Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Sealing Criteria, Concepts, and Designs (1.2.2.4)

Activity S.3.3.6
BRINE INFLOW SCALE AND STRATUM EFFECTS

1. Focus

It is necessary to measure the effect of excavation scale, age, and stratigraphy on brine inflow as a further test of the current brine inflow model (Nowak and McTigue, 1987). The scale effect is predicted by the current model. A scale effect is a consequence of the predominant brine transport mechanism, and a model is necessary to quantify that effect (Activities S.3.2.4 and S.3.2.5). A complete model of brine inflow will include the potential for brine-inflow heterogeneity from different strata and from excavations of different ages. Brine inflow to horizontal boreholes in the host rock as well as vertical boreholes above and below the facility horizon can be measured by collecting and weighing the brine. Brine inflow rates as a function of borehole size for comparison with predicted scale effects must be measured. The difference in brine inflow rates among identifiably different strata in the disposal horizon must be measured to assess the magnitude of the effect of host rock heterogeneity. In addition, the effect of excavation age must be measured.

2. Methodology

Existing and new boreholes will be monitored to measure and compare brine inflow rates and trends. The boreholes range in diameter from 4 to 36 in. (10 to 91 cm) and penetrate various strata. The measured versus predicted scale effects on brine inflow will be compared to assess the consistency of the model with in situ conditions. Compositions of brine sampled will be determined.

3. Information Needs Addressed

Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Salado Formation (1.3.2.1)

Activity S.3.3.7
PORE PRESSURE FOR BRINE INFLOW

1. Focus

Pore-pressure gradients near excavations and in the far-field are essential data for testing our concepts of the brine-inflow mechanism (Nowak and McTigue, 1987; McTigue and Nowak, 1987) (Activities 3.2.4, 3.2.5).

The current Darcy-like flow model for brine inflow can be used to predict near-field pore-pressure gradients for comparison with data. Far-field pore-pressure values may gauge the extent to which brine-flow paths in the WIPP host rock are interconnected. Because pore-pressure measurements require brine inflow to a test zone, data on brine-inflow rate versus rock pressure are also obtainable. Permeability values and relationships between inflow rate and pore-pressure difference can also be inferred from these data. Pore pressures and inferred permeabilities measured at different depths and locations may indicate any significant heterogeneity in the host rock and any potentially preferred brine-transport paths.

2. Methodology

This effort will concentrate on obtaining an integrated set of data for the brine-inflow excavated room (Activity S.3.3.8). Pore pressure (including the test-interval pressure rise) will be measured in 4-in. (10-cm) diameter test boreholes using tools designed and manufactured specifically for that purpose. The tools measure borehole closure and pressure simultaneously in the test intervals. All vertical and some horizontal boreholes will contain single-completion instruments. The end of the borehole will be sealed with a double packer to create the test interval. The volume between the packers serves as a guard zone to detect leakage past the primary packer. The pressure rise will be measured with a transducer. Several horizontal boreholes will contain multiple-completion instruments, in which multiple test zones are created in a single borehole within a uniform stratum.

Test intervals will be 3 ft to 65 ft (1 m to 20 m) from WIPP excavation walls. Test zones are planned to include measurements in, above, and below the disposal horizon. Anhydrite beds (e.g., Marker Bed 139) and clay beds (or seams) will be included among the test intervals.

The first set of data will be obtained while the circular-cross-section brine room is bored and passes by the pore-pressure test locations. Pore-pressure data will also be obtained during the brine-inflow test in the circular room and after the room is enlarged to a rectangle in Phase 2 of the brine-inflow room test.

3. Information Needs Addressed

Brine Inflow and Room Resaturation
(1.2.1.5)
Disturbed Rock Zone and Fluid-Flow
Characteristics (1.2.4.3)
Salado Formation (1.3.2.1)

Activity S.3.3.8
BRINE INFLOW TO EXCAVATED ROOMS

1. Focus

It is important to test the scale-up capability of the brine-inflow model from small (4- to 36-in. [10- to 91-cm] diameter) boreholes to excavations having diameters of several feet and intercepting most of the proposed waste disposal horizon (Nowak and McTigue, 1987). Experimental excavations with a characteristic size of several feet are needed to test scale-up with the model and to sample a representative portion of host rock salt.

Data from this brine flow test will be used to test the current brine inflow model with regard to scale-up from boreholes to room size excavations. The results may be useful in differentiating among potential mechanisms and corresponding models for brine flow (Activities S.3.2.4 and S.3.2.5). Data obtained will characterize the excavation induced disturbed zone without including the complexities of Marker Bed 139, an anhydrite interbed several feet below the proposed waste disposal horizon. Possible effects of Marker Bed 139 on brine inflow and on the disturbed zone may be measured separately in a second phase of testing.

A room with a circular cross section is expected to maximize the fraction of incoming brine that can be collected in instrumented containers and measured directly without the need to infer brine volumes. In this way, the circular cross section addresses the possibility that inaccuracies in brine inflow measurements to test rooms could result from the accumulation of brine in fractures surrounding the room, particularly in the underlying Marker Bed 139 and overlying seams. This curved cross section may also minimize the disturbed zone on the surrounding host rock, further minimizing occurrences of undetected incoming brine.

2. Methodology

As a circular brine-inflow room is bored, instrumentation will measure the pore-pressure response of the host rock. After the room is excavated and sealed, remotely read instrumentation will collect data on humidity, closure, pore pressure vs. distance from the wall, and other variables. The disturbed zone will be characterized using methods such as electrical conductivity and acoustic measurements. Liquid brine inflow will be collected from troughs and shallow sumps to be weighed, measured, and analyzed. Salt samples will also be analyzed for brine content. Finally, posttest studies will be conducted including analyses of core samples and measurements in exploratory boreholes. The data will then be interpreted in terms of brine transport mechanisms.

3. Information Needs Addressed

Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Salado Formation (1.3.2.1)

Activity S.3.3.9
BRINE PERMEABILITY TESTING OF THE DISPOSAL HORIZON

1. Focus

This testing will reduce the uncertainty in permeability values for the far-field domain of the Salado Formation and will support seal and backfill design. The rate of brine seepage into the facility, although influenced by near-field transient effects, will be, in the long term, controlled by the far-field permeability. The degree and rate of backfill consolidation will be influenced by brine inflow. Activities S.3.2.4, S.3.2.6, S.3.3.4, S.3.3.5, S.3.3.6, S.3.3.8, S.3.3.9, S.3.3.10, S.3.3.11, S.3.3.12, and S.3.3.13 combine into an overall approach to the hydrologic behavior and characterization of the disposal horizon. The testing in this activity delineates the extent of the hydrologically disturbed zone by comparing results with those obtained in near-field activities. Data on the permeability of different zones in the Salado Formation when undisturbed by the presence of the excavation will be obtained.

2. Methodology

Ten to fifteen locations will be identified to drill an array of five holes, including vertical (up and down), subhorizontal, and inclined holes. Permeability tests will be conducted at various intervals from 10 to 50 ft (3 to 15.2 m) from the facility in the halites, polyhalites, anhydrites, and clay interbeds. The data will resolve the above mentioned uncertainties and will be used in the mechanistic modeling (Activity S.3.2.5).

3. Information Needs Addressed

Brine Inflow and Room Resaturation (1.2.1.5)
Disturbed Rock Zone (1.2.1.7)
Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.2.1)
Disturbed Rock Zone (1.2.3.2)
Salado Formation (1.3.2.1)
Rustler/Salado Formation (1.3.2.3)

Activity S.3.3.10
AIR INTAKE SHAFT BRINE PERMEABILITY TESTING

1. Focus

Pressure changes measured in the Rustler Formation behind the shaft liner are either due to changes in leakage rates into the shaft or to hydrologic testing being conducted around the site (Activity S.4.3.2, Beauheim, 1987a; Haug et al., 1987). These pressure changes could affect the successful sealing of the shaft if fluid bypasses the seals in a zone of higher permeability. The Rustler and Salado Formations around the shaft must be characterized with respect to their ability to provide fluids to the shafts. Long-term pressure data are also required to evaluate changes in the hydrologic regime around the shaft. Data and interpretations appropriate for use in shaft seal design (Activity S.2.2.2) and three-dimensional mechanistic modeling (Activity S.3.2.5) are required.

2. Methodology

Three subhorizontal holes will be drilled and tested at each of eleven levels in the Air Intake Shaft. The levels include six water-bearing horizons above the Salado Formation and five horizons in the Salado. The holes will extend about 50 ft (15.2 m) outward, and permeability testing of at least three intervals will be conducted. At least one borehole in each horizon will be completed for long-term pressure and borehole closure monitoring. One to two years after completion of the testing, selected holes will be retested to assess whether any changes in the disturbed zone have occurred.

3. Information Needs Addressed

Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Sealing Criteria, Concepts, and Design (1.2.4.5)
Salado Formation (1.3.2.1)
Rustler/Salado Formation (1.3.2.3)
Rustler Formation (1.3.2.4)
Rustler/Dewey Lake Red Beds (1.3.2.6)
Borehole Plug Interactions (1.3.4.2)

Activity S.3.3.11
SHAFT GEOPHYSICS

1. Focus

Variations in seismic velocity and electrical resistivity can be used to monitor the development of fractures and changes in porosity and permeability around a shaft for input into the disturbed rock zone model (Activity S.3.2.6). Geophysical methods can investigate the first 3 to 6 ft (1 to 2 m) of the wall rock to delineate the disturbed rock zone and stratigraphic variations in water content and porosity. This will provide data on the nature of the rock at the proposed seal locations. These methods could monitor changes in resistivity and seismic velocity around large-scale seal tests to provide a performance measure for seal design.

2. Methodology

The design for the electromagnetic and refraction studies must be completed; then refraction stations will be installed in the Air Intake Shaft. An initial electromagnetic survey will be conducted in the Salado Formation in the shaft. Periodic resurveys in the shaft would then be conducted with both refraction and electromagnetic methods.

3. Information Needs Addressed

Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Salado Formation (1.3.2.1)

Activity S.3.3.12
UNDERGROUND GEOPHYSICS

1. Focus

The geophysical techniques previously described (Activity S.3.3.11) can also be used to investigate back-filled rooms, the facility host rock, and proposed seal locations. Electrical and seismic methods can be used to remotely measure changes in density, void volume, and moisture. Variations in permeabilities relative to depth and position in the facility will provide indications where additional detailed testing might be conducted.

2. Methodology

Experimental high-resolution refraction surveys will be conducted, and an experimental remotely-monitored electromagnetic system will be initiated. These systems can be refined if needed and provide support tools for other performance assessment activities.

3. Information Needs Addressed

Backfill (1.2.1.2)
Container Response (1.2.1.3)
Closure (1.2.1.4)
Disturbed Rock Zone (1.2.1.7)
Disturbed Rock Zone (1.2.3.2)
Salado Formation (1.3.2.1)

Activity S.3.3.13
BRINE SAMPLING AND EVALUATION PROGRAM

1. Focus

The Brine Sampling and Evaluation Program characterizes the extent and composition of visually identified brine inflow. This will assist in evaluating brine sources, areal extent and volume of existing and potential brine, relationships between brine and gas occurrences, and the long-term behavior of known occurrences. This activity supports the modeling of brine inflow to the facility (Activities S.3.2.4 and S.3.2.5).

2. Methodology

Photographic documentation of brine weeps as well as observation and measurements of brine accumulations in drill holes has been ongoing for over five years and will be continued. The existing data document the variation in moisture content that occurs stratigraphically, laterally, and with time since the areas were mined. Salt efflorescences will be dried and weighed to determine the quantity of brine that evaporated to form the deposits. Visual and geophysical logging of boreholes will assist in delineating specific zones of higher moisture content. Brine samples will be collected periodically and the chemical composition analyzed.

3. Information Needs Addressed

Brine Inflow and Room
  Resaturation (1.2.1.5)
Salado Formation (1.3.2.1)

2.7.2.4 Non-Salado Formation Hydrology and Nuclide Migration Activities

This section describes the activities involving non-Salado hydrology and nuclide migration (Table 2-6). Figure 2-9 illustrates the manner in which this technical area provides input necessary for performance assessment. Transport of radionuclides to the accessible environment is the ultimate concern of WIPP performance assessment. The Rustler Formation contains the first laterally continuous water-bearing zone above the WIPP repository horizon, the Culebra Dolomite Member. For this reason, evaluation of the Rustler Formation, and especially the Culebra Dolomite Member, has been a major focus of WIPP site characterization (Lappin, 1988). The final stages of testing, interpretation, and numerical modeling of the physical hydrology, radionuclide transport, and geochemical behavior of the Rustler Formation form the major focus of this area. Some data will be collected from the interval between the WIPP repository horizon and the Rustler Formation.

One group of activities in this section will collect data and report them for the final numerical model describing the present day hydrology of the Culebra Dolomite at and near the WIPP site. This model will directly support regional-scale performance assessment calculations. The major activities include a multipad interference test at the H-11 hydropad and monitoring of the Rustler Formation's response to installation of the WIPP Air Intake Shaft; both activities are ongoing.

A second group of activities will determine the relevant radionuclide-transport mechanisms that must be considered by performance assessment in modeling transport between the WIPP repository horizon and the accessible environment through the Rustler Formation. Regional scale calculations have already been completed for transport through the Culebra Dolomite Member under undisturbed conditions (Reeves et al., 1987). Major Rustler Formation field and modeling activities remaining to be completed include the conservative-tracer test at the H-11 hydropad, final reporting of all conservative-tracer testing completed to date, and completion of regional scale Culebra transport calculations under disturbed conditions, analogous to calculations contained in Reeves et al. (1987). Laboratory activities will provide updated data and an understanding of the reliability of radionuclide retention mechanisms within the Rustler Formation.

The third group of activities directly supports the required consideration of a 10,000-year time frame in regional scale radionuclide transport. Major focuses include geochemical and geophysical studies, in addition to limited hydrologic studies of units above and below the Rustler Formation. The studies are largely an outgrowth of completed studies indicating the transient nature of WIPP hydrology (e.g., Lambert, 1987; Lambert and Harvey, 1987). Because the studies address how the hydrologic and geochemical settings of the Rustler Formation have changed over about the past 10,000 years, the results can be used to indicate defensible boundary conditions for modeling studies addressing hydrology and nuclide migration over the next 10,000 years.

Table 2-6. Applications of the Non-Salado Formation Hydrology and Nuclide Migration Investigations

Program-Area Activity	Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.4.1 Laboratory Studies:				
S.4.1.1 Batch K_d Measurements	Backfill Performance, Radionuclide Retardation*			Radionuclide Retardation
S.4.1.2 Mechanistic Studies of Sorption	Backfill Performance, Getter Effectiveness			Radionuclide Retardation
S.4.1.3 Solute Column Transport	Radionuclide Transport*			Radionuclide Retardation
S.4.1.4 Rustler Radiocarbon				Ground-Water Flow, Rustler Hydrologic Properties
S.4.1.5 Mineralogical and Hydrochemical Studies in Support of Sorption Experiments				Radionuclide Retardation, Rustler Chemical Properties
4.2 Modeling Studies:				
S.4.2.1 Final 2-D Culebra Modeling				Ground-Water Flow, Radionuclide Transport, Hydrologic Properties
S.4.2.2 Solute Transport - Brine Reservoir Breach Into the Culebra				Ground-Water Flow, Radionuclide Transport, Hydrologic Properties

*Denotes a secondary application

Table 2-6. Applications of the Non-Salado Formation Hydrology and Nuclide Migration Investigations (Continued)

Program-Area Activity	Phenomena/Parameters Being Addressed			
	Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.4.2.3 Far-Field Hydrologic Flow and Boundary Conditions				Ground-Water Flow, Radionuclide Transport, Culebra Hydrologic Properties
S.4.2.4 Far-Field Culebra Transport Mechanisms Under Disturbed and Undisturbed Conditions				Ground-Water Flow, Radionuclide Transport, Culebra Hydrologic Properties
S.4.3 In Situ Tests:				
S.4.3.1 H-11 Multipad/Tracer Test				Ground-Water Flow, Radionuclide Transport, Culebra Hydrologic Properties
S.4.3.2 Rustler Response to Air Intake Shaft		Seal Performance*		Ground-Water Flow, Hydrologic Properties
S.4.3.3 Single-Hole Hydraulic Tests of the Rustler Formation				Ground-Water Flow, Hydrologic Properties
S.4.3.4 Single-Pad Interference Tests of the Culebra Dolomite				Ground-Water Flow, Hydrologic Properties

*Denotes a secondary application

Table 2-6. Applications of the Non-Salado Formation Hydrology and Nuclide Migration Investigations (Concluded)

Program-Area Activity	Phenomena/Parameters Being Addressed: Disposal Room and Drift System	Sealing System	Structural and Fluid Flow Behavior, Salado	Hydrology and Nuclide Migration, Non-Salado
S.4.3.5 Conceptual Hydrogeologic Model of the Rustler Formation				Hydrologic Properties, Rock Properties
S.4.3.6 Bell Canyon Hydrologic Information				Hydrologic Properties
S.4.3.7 Dewey Lake Red Beds Hydrology				Hydrologic Properties
S.4.3.8 Surface Geophysics		Seal Performance*		Rustler Rock Properties
S.4.3.9 Regional Geochemical Studies: Solute Chemistry and Mineralogy				Rustler Rock Properties
S.4.3.10 Regional Geochemical Studies: Dissolution				Rustler Rock Properties
S.4.3.11 Regional Geochemical Studies: Paleoclimate				Climate Properties

*Denotes a secondary application

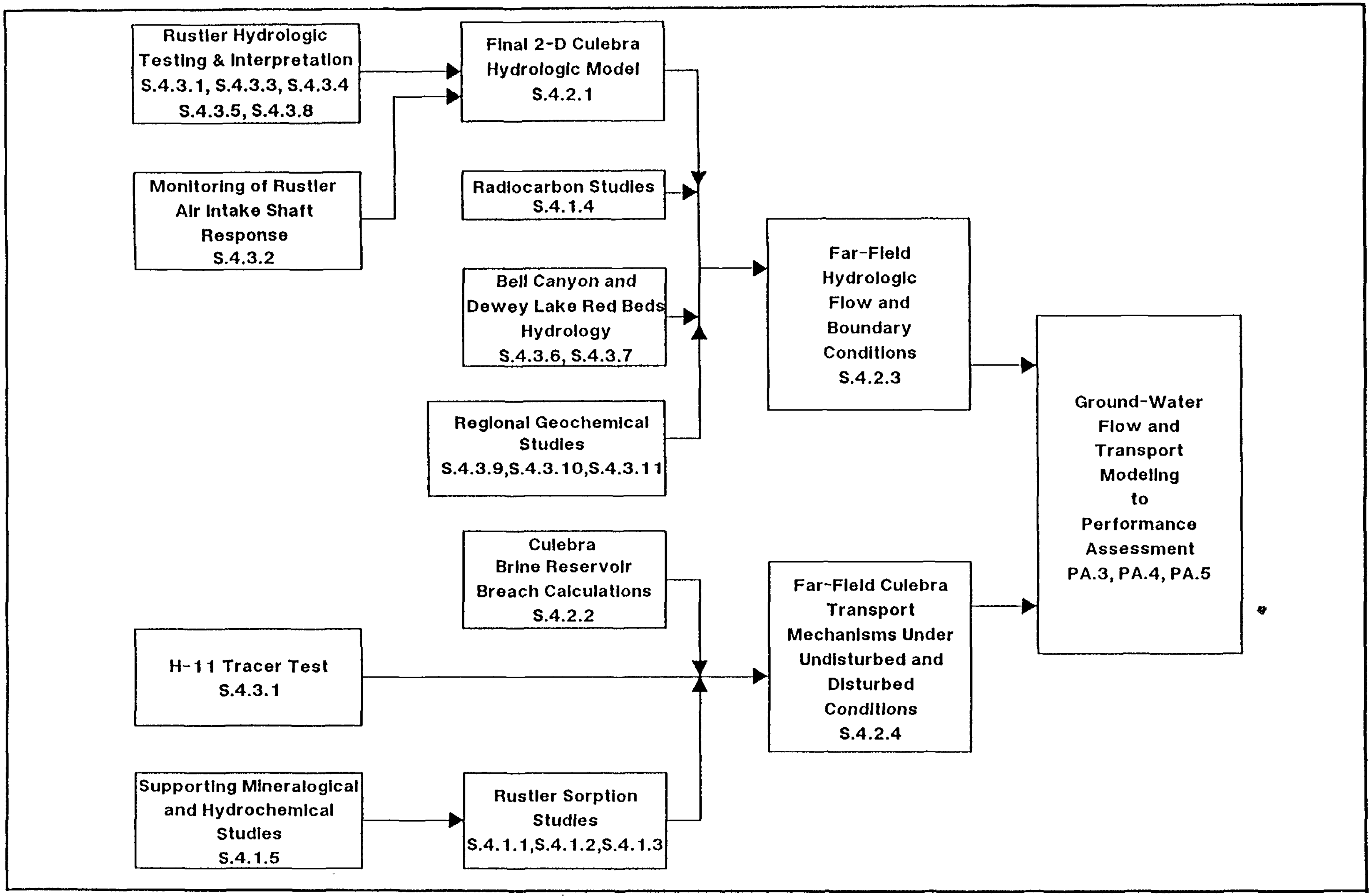


Figure 2-9. Relationship Among Non-Salado Formation Hydrology and Nuclide Migration Activities

Activity S.4.1.1
BATCH K_d MEASUREMENTS

1. Focus

Broad-based semiempirical data on radionuclide retention within the Rustler Formation are needed for radionuclide release scenarios. Batch K_d measurements will be conducted for specific Culebra ground water/rock combinations relevant to the WIPP performance assessment. Along with basic models and data developed in S.4.1.2, measured K_d values will be extrapolated to natural conditions for release.

Data are insufficient to determine whether K_ds obtained during previous batch studies were due to sorption or other chemical processes occurring during the experiment. New experiments must be carefully designed to ensure that potentially important speciation effects are not overlooked. Batch sorption data will be obtained for plutonium, lead, and uranium under a range of experimental conditions with natural materials.

2. Methodology

The available literature describing sorption of radionuclides on rocks from the WIPP site and generic clays, sulfates, and carbonates in saline waters or in the presence of organic ligands (complexing agents) will be reviewed. The batch K_d experiments will be designed to avoid the problems identified by the literature review. An experimental factorial matrix will be designed to examine effects of mineral composition, brine composition, and radionuclides concentration.

Radionuclide sorption will also be qualitatively studied by contacting rock slabs with radionuclide-doped solutions and examining the locations of fission tracks or fogging of photographic film laid on top of the sample. The purpose will be to identify sites of radionuclide uptake on whole rock samples for a large number of combinations of radionuclides, organics, major solutes, and well-characterized rocks.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)

Activity S.4.1.2
MECHANISTIC STUDIES OF SORPTION

1. Focus

Extrapolation of K_d measurements (Activity S.4.1.1) and the conduct and interpretation of fracture flow or column experiments (Activity S.4.1.3) must be done on a defensible basis. K_d values are valid only for the specific conditions of the experiment. Therefore, it is necessary to obtain a defensible theoretical understanding of the mechanisms of radionuclide/rock interactions for several simple systems relevant to WIPP. The information will be used to design batch K_d experiments and column studies to ensure that potentially important speciation or complexation effects are not overlooked in the performance assessment calculations.

2. Methodology

Techniques to measure the site-binding capacity of carbonates, sulfates, and clays in WIPP waters as a function of pH, redox ionic strength, and other solution chemistry variables must be developed. Stability constants for potentially important complexes of plutonium, uranium, and lead in WIPP ground waters must be obtained, and sites of uptake radionuclides and heavy metals such as lead must be identified for clays, sulfates, and carbonates. Studies of rates of sorption, coprecipitation, and matrix diffusion important to radionuclide retardation must be implemented. These studies will all increase confidence in the ability to make long-term predictions of radionuclide and heavy metal transport at the WIPP facility (Activity S.4.2.4).

3. Information Needs Addressed

Backfill (1.2.1.2)
Culebra Dolomite Member (1.3.2.2)

Activity S.4.1.3
SOLUTE COLUMN TRANSPORT

1. Focus

Batch K_d experiment data and column transport data will provide radionuclide sorption values for use in predictions of radionuclide transport through water-bearing units at the WIPP site (Activity S.4.2.4).

Available K_d and column data are inadequate for the needs of performance assessment. There are few data from column experiments on WIPP materials, the available data are not for radionuclides of interest, and the solutions used in the experiments contained no organic complexants. Additional column-experiment data will support performance assessment; new experiments must be carefully designed to ensure that potentially important speciation effects within the fluid are not overlooked. The column experiments will form the final experimental evaluation of the transport behavior within the Culebra Dolomite.

2. Methodology

Wafer and column transport experiments for a small number of radionuclide/organic/rock/water combinations will be guided by information obtained from Activities S.4.1.1 and S.4.1.2. The studies will differ from previous column studies in that more relevant experimental material will be used. In addition, greater care will be taken to (1) account for the fate of all of the radionuclides introduced in the experiments (mass balance), (2) characterize the solids involved in sorption, (3) avoid supersaturation or complexation by agents not expected in waters at WIPP, and (4) design and bound flow conditions to ensure that matrix diffusion can be accounted for in the final data interpretation. The theoretical calculations of radionuclide transport in the columns will be applicable to chemical systems typical of the WIPP site and facility.

A coupled chemical reaction/transport code to model the results of column experiments is required. Such a code is currently under development at Oak Ridge National Laboratory with partial support from Sandia National Laboratories. The code will be adapted for this project and will be used to calculate theoretical elution curves for the columns using basic thermodynamic and kinetic data.

3. Information Needs Addressed

Backfill (1.2.1.2)
Culebra Dolomite Member (1.3.2.2)

Activity S.4.1.4
RUSTLER RADIOCARBON

1. Focus

Data resulting from this activity may better establish the magnitudes of uncertainties in radiocarbon activity measurements arising from (1) natural variability of less heavily organic contaminated sampling localities with time, (2) transient variability of moderately to heavily organic contaminated sampling localities as a function of degree of purging, and (3) variability among different modes of sample preservation and sample storage times.

The primary use of radiocarbon analysis of Rustler ground waters (Lambert, 1987) has been in the attempt to determine ground-water residence times at the WIPP site. The results to date (Lambert and Harvey, 1987; Lambert and Carter, 1987) are consistent with the interpretation that the overall hydrologic setting of the WIPP site is transient (Activity S.4.2.3).

2. Methodology

Water samples will be collected and analyzed from six wells chosen to represent a spectrum of degrees of organic contamination based on experience from WIPP water sampling programs. Samples collected will address questions on organic contamination, precision of sampling, preservation methods, and sample shelf life. Eighteen archived radiocarbon samples will be analyzed for comparison. Finally the integrity of samples stored for over three years before being analyzed will be verified.

3. Information Needs Addressed

Recharge (1.3.1.6)
Culebra Dolomite Member (1.3.2.2)

Activity S.4.1.5
MINERALOGICAL AND HYDROCHEMICAL STUDIES IN SUPPORT OF SORPTION EXPERIMENTS

1. Focus

Results of laboratory studies of radionuclide transport (Activities S.4.1.1 - S.4.1.3) may be difficult to extrapolate to the complex environments at the WIPP and to the long time periods considered by the EPA Standard. Natural analogs of nuclide behavior in the solute systems present at the WIPP can provide valuable data for the validation of models of the long-term behavior of radionuclides under natural conditions.

Laboratory studies of radionuclide sorption and transport (Activities S.4.1.1 - S.4.1.3) can be applied to predictions of performance of the WIPP facility only if the data have been collected under the physiochemical conditions relevant to the natural system. Important characteristics of the ground water and minerals that would react with radionuclides released from the facility are uncertain. Important solution parameters include the saturation state of the waters with respect to the dominant carbonate and sulfate minerals; pH; pCO_2; and redox equilibria. Previous studies of Rustler Formation mineralogy have focused on detailed aspects of clays in a few well-documented intact cores. Sampling bias inherent in such a focus is present because principal water-bearing zones, commonly a fraction of the whole thickness of the Culebra Dolomite Member, are likely to have been reduced to rubble by partial dissolution and hence were poorly represented in core recovery. Additional rock samples containing surfaces previously in contact with ground waters will be obtained.

2. Methodology

The component tasks in this effort are (1) collecting shaft samples or core fragments likely to have been exposed to natural occurrences of fluid for use in sorption experiments, (2) mineralogical determinations on the core, including petrographic examination, analyses of organic carbon, X-ray diffraction, and electron optics studies, (3) measuring total CO_2 content and improving estimates of the pH and carbonate mineral/water equilibria of Culebra waters, (4) evaluating the nature of redox disequilibria of the Culebra, (5) formulating a natural analog model to understand the behavior of naturally occurring uranium in the Rustler Formation to complement theoretical and experimental studies of uranium sorption and speciation at the WIPP site, and (6) completing Rb/Sr dating studies of clay minerals in the Salado Formation to determine the last episode of pervasive fluid movement through Salado rocks that resulted in mineral alteration.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)

Activity S.4.2.1
FINAL TWO-DIMENSIONAL CULEBRA MODELING

1. Focus

A numerical ground-water model that demonstrates quantitative understanding of the present day Culebra flow regime and investigates the sensitivity of model results to data uncertainties is necessary to understanding radionuclide transport in the Culebra Dolomite Member. This model must also demonstrate a quantitative understanding of possible long-term changes in the flow system associated with climatic change or with other transient changes in boundary conditions (Activity S.4.2.3).

This model will be used as the mechanistic hydrologic model for the Culebra Dolomite Member at and near the WIPP site (Activities PA.3 and PA.4) and will be the basis for regional scale transport calculations.

The Culebra Dolomite is the most transmissive laterally continuous hydrogeologic unit above the WIPP facility. It is considered to be the major potential off-site pathway for radionuclide transport in the subsurface, should a breach of the facility occur. Past modeling studies have focused on developing a calibrated model of the flow regime for approximately steady-state head conditions and for simulating two multipad-scale interference tests.

2. Methodology

Continuing work extends model calibration to include the transient hydraulic stresses caused by Air Intake Shaft construction and the H-11 multipad/tracer test (Activity S.4.3.1) and other new data from other single well and single-pad hydrologic tests. Model calibration will use an adjoint-sensitivity approach that provides feedback on the sensitivity of simulated heads at observation wells as a function of variations in the transmissivity distribution. This feedback will significantly enhance the calibration process.

Uncertainties in the final calibrated model of the present day flow regime, including travel time uncertainty between the WIPP site center and southern boundary, will be quantitatively estimated.

After the model has been calibrated and the present-day flow regime can be simulated satisfactorily, the model will be extended to simulate possible long-term changes in the Culebra flow system associated with climatic change. These simulations will be implemented by coupling the Culebra model with the regional-scale Culebra model and with the upper portion of the three-dimensional model being constructed as part of Activity S.3.2.5. This coupling will allow the examination of the hydrologic impact including travel time of various climate-related scenarios over 10,000 years.

3. Information Needs Addressed

Recharge (1.3.1.6)
Culebra Dolomite Member (1.3.2.2)
Rustler/Salado Formations (1.3.2.3)
Rustler Formation (1.3.2.4)
Rustler/Dewey Lake Red Beds (1.3.2.6)

Activity S.4.2.2
SOLUTE TRANSPORT-BRINE RESERVOIR BREACH INTO THE CULEBRA

1. Focus

One group of WIPP scenarios includes breach of the facility by drilling into an underlying pressurized brine occurrence in the Castile Formation. This activity supports calculations needed to evaluate flow and transport in the Culebra Dolomite Member following such a breach and calculations of releases resulting from these breach scenarios.

Breaches of the WIPP facility that involve injection of contaminated fluids into the Culebra Dolomite Member and their subsequent transport to the accessible environment can be bounded by two pressure conditions at the injection point: low-pressure injection that does not disturb the natural hydraulic gradients within the Culebra Dolomite Member, and high-pressure injection that substantially alters the hydraulic gradients. An example of a high-pressure injection would be a connection between the Culebra and a Castile pressurized brine occurrence. Reeves et al. (1987) evaluated the relative importance of the parameters governing solute transport through double-porosity portions of the Culebra under a low-pressure injection scenario. They showed that under the gradients naturally occurring within the Culebra, diffusion of solutes from the fractures to the rock matrix may lead to an overall regional-scale transport behavior similar to that of a simple porous medium. Whether this same conclusion applies in the case of a high-pressure injection scenario is unknown and must be resolved. This activity will provide information on transport mechanisms and approaches for far-field modeling of disturbed conditions.

2. Methodology

The areal, steady-state ground-water flow field of the Culebra Dolomite Member derived from modeling will be used as the initial condition for simulating ground-water flow and solute transport for a high-pressure injection scenario. An internal boundary condition in the model will dynamically link a well connecting a Castile pressurized brine occurrence to the Culebra Dolomite at a point above the disposal panels. Transient simulations will be used to define the resulting time-dependent changes in the flow field. Based on hydraulic testing of existing pressurized brine occurrences, a range of parameter values governing brine-reservoir behavior will be used.

To examine solute transport under high hydraulic gradients, a number of flow paths from the breach point to the accessible environment will be selected for further study. Dual-porosity transport will be examined under a variety of conditions. Free-water diffusivity, matrix tortuosity, matrix-block length, matrix porosity, fracture porosity, fracture dispersivity, fracture flux, and sorption will be varied systematically over their ranges of uncertainty to establish their relative importance in affecting solute travel times. Comparisons will be made to solute transport through a simple porous medium under the same hydraulic conditions. If the results of the numerical modeling indicate that transport through the Culebra Dolomite Member in the event of a brine-reservior breach is of concern, then it will be necessary to compile and assess available data on the composition of Castile brines.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)
Castile Formation Brines (1.3.2.7)
Pressurized Brine Hydrofracturing and Transport (1.3.2.8)

Activity S.4.2.3
FAR-FIELD HYDROLOGIC FLOW AND BOUNDARY CONDITIONS

1. Focus

Site characterization activities which have emphasized the Rustler Formation and shallower units indicate that the geohydrologic setting of the WIPP site is transient on the 10,000-year time scale of regulatory interest. For performance assessment calculations, the extent of time-dependent variations in hydrologic flow and boundary conditions for all water-bearing units of interest over 10,000 years must be estimated. The units of interest extend from the surface downward through the Bell Canyon Formation.

2. Methodology

This activity will compile and examine recommendations on time-dependent boundary conditions and flow behaviors for individual stratigraphic units and develop an internally consistent description of the overall time-dependent hydrologic behavior of the WIPP region for input directly into Performance Assessment. The modeling of the hydrology of the Rustler Formation will be completed. The Bell Canyon, Salado, and Dewey Lake Red Beds hydrologic information will be correlated with paleoclimate information and its estimated effects within the Rustler Formation.

3. Information Needs Addressed

Recharge (1.3.1.6)
Extent of Dissolution (1.3.1.7)
Culebra Dolomite Member (1.3.2.2)
Rustler/Salado Formation (1.3.2.3)
Rustler Formation (1.3.2.4)
Dewey Lake Red Beds (1.3.2.5)
Rustler/Dewey Lake Red Beds (1.3.2.6)
Pressurized Brine Hydrofracturing and Transport (1.3.2.8)
Bell Canyon (1.3.2.9)

Activity S.4.2.4
FAR-FIELD CULEBRA TRANSPORT MECHANISMS UNDER DISTURBED AND UNDISTURBED CONDITIONS

1. Focus

Testing with conservative tracers at the borehole hydropads has demonstrated the important role of fractures in controlling the transport of conservative "contaminants" on at least the 164 to 492 ft (50 to 100 m) scale in fractured portions of the Culebra Dolomite Member. To reduce uncertainty in transport modeling, it is necessary to determine whether such fracturing also plays a significant role in transport to the accessible environment through fractured portions of the Culebra Dolomite, under both undisturbed and brine-reservior-breached conditions.

2. Methodology

This activity examines the importance of various mechanisms for radionuclide transport through the Culebra Dolomite from a point above the WIPP waste-emplacement panels to the accessible environment. Final interpretations of conservative-tracer tests at the three hydropads will be completed. These interpretations will estimate effective block sizes and effective fracture porosities within fractured portions of the Culebra Dolomite. Completed calculations investigating the role of fractures under undisturbed conditions (Reeves et al., 1987) use a preliminary transmissivity distribution within the Culebra Dolomite (Haug et al., 1987) and preliminary estimates of fracture spacings and porosities (Kelley and Pickens, 1986). The conclusions of Reeves et al. (1987), namely that fracturing effects need not be included in numerical modeling of transport to the accessible environment within the Culebra Dolomite under undisturbed conditions, will be examined in light of the final estimated transmissivity distribution (Activity S.4.2.1) and effective block sizes and fracture porosities.

Ongoing calculations are examining the potential effects of fracturing on transport within the Culebra Dolomite following a brine-reservoir breach of the WIPP facility (Activity S.4.2.2). Conclusions based on these calculations, which use the Culebra Dolomite transmissivity distribution estimated by LaVenue et al. (1988), will be examined in light of the final estimated Culebra Dolomite transmissivity distribution, fracture spacings, and fracture porosities provided by Activity S.4.2.1. The result will be a final estimate of the importance of various transport mechanisms within fractured portions of the Culebra Dolomite under both undisturbed and brine-reservoir-breached conditions, with emphasis on determining whether transport through fractures plays any significant role on the regional scale.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)
Castile Formation Brines (1.3.2.7)
Pressurized Brine Hydrofracturing and Transport (1.3.2.8)

Activity S.4.3.1
H-11 MULTIPAD/TRACER TEST

1. Focus

Large-scale testing at the H-11 hydropad, similar to multipad pump and tracer tests performed elsewhere at WIPP (Beauheim, 1987a; Beauheim, 1987b), will better define the extent and properties of the relatively higher permeability zone within the Culebra Dolomite in the southeastern part of the WIPP site. Numerical modeling of ground-water flow in the Culebra Dolomite (LaVenue et al., 1988) shows that water above WIPP generally flows southward. This flow is controlled by a high-permeability zone. Because transport of solutes through this zone is of concern (Reeves et al., 1987), tracer tests should address this sensitive portion of the site. Computer analysis of the data will estimate fracture porosity and other factors for use in solute-transport modeling. The distribution of transmissivities and storativities resulting from the analysis will guide the two-dimensional numerical modeling of Culebra Dolomite flow (Activity S.4.2.1).

2. Methodology

A combination multipad pumping and tracer test was performed at the H-11 hydropad. Different tracers were injected into the three other wells on the hydropad and their breakthroughs to the pumped well were monitored to allow characterization of the flow paths. Water levels were also monitored in surrounding observation wells to define the water recovery trends. Analysis of these data will be input to the modeling activities to better define the high-permeability zone in the Culebra Dolomite.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)

Activity S.4.3.2
RUSTLER RESPONSE TO AIR INTAKE SHAFT

1. Focus

Monitoring and interpretations of the hydrologic response as a result of the installation and grouting of the Air Intake Shaft are necessary to develop the final Culebra model (Activity S.4.2.1) and to support the near-field, mechanistic, flow and transport model (Activity S.3.2.5). The drawdown cone caused by leakage from the Culebra into the shafts extends at least 2 mi (3.2 km) outward (Haug et al., 1987). Field data will be interpreted and simulated using computer models to estimate transmissivity and storativity for Rustler members at the WIPP facility. These data will allow calculation of potential leakage rates to the shafts, better design of shaft seals, and more defensible undisturbed performance calculations.

2. Methodology

Because the storativity and transmissivity within the Rustler can only be clarified by long-term testing, a specific borehole (H-16) was drilled and instrumented to monitor the hydrologic regime, both during construction and after construction of the Air Intake Shaft. Pressures in all five Rustler members were monitored, and water level measurements in nearby observation wells were monitored (Beauheim, 1987c). These data will provide support in developing the final Culebra model.

3. Information Needs Addressed

Disturbed Rock Zone and Fluid-Flow Characteristics (1.2.4.3)
Culebra Dolomite Member (1.3.2.2)
Rustler Formation (1.3.2.4)
Rustler/Dewey Lake Red Beds (1.3.2.6)

Activity S.4.3.3
SINGLE-HOLE HYDRAULIC TESTS OF THE RUSTLER FORMATION

1. Focus

   Additional single-hole hydrologic data on the Rustler Formation are needed to reduce uncertainties in the hydrologic data bases. A reliable numerical model of ground water flow and mass transport through the Culebra Dolomite must be completed. Previous tests and modeling have identified areas where Culebra Dolomite observation wells would be useful (LaVenue et al., 1988).

2. Methodology

   Seven boreholes located in response to previous tests and modeling have been drilled and tested (Beauheim, 1987c). The data from these tests will be interpreted from pump tests or slug tests and transmissivity in high-uncertainty locations in the Culebra Dolomite will be estimated. Data will be incorporated into the appropriate Culebra Dolomite models (Activity S.4.2.1). If unacceptable areas of uncertainty still exist, additional boreholes may be required. It is likely that a new Culebra-depth hole south of the WIPP facility and a shallow hole into the Dewey Lake Red Beds will be required.

3. Information Needs Addressed

   Culebra Dolomite Member (1.3.2.2)
   Rustler Formation (1.3.2.4)
   Rustler/Dewey Lake Red Beds (1.3.2.6)

Activity S.4.3.4
SINGLE-PAD INTERFERENCE TESTS OF THE CULEBRA DOLOMITE

1. Focus

A reliable and defensible numerical model of ground-water flow and transport through the Culebra Dolomite is required for final interpretation of the local variability of fracturing effects and storativity on ground-water flow. Results to date identify the existence of fracturing in several boreholes and demonstrate the complex relationship between fracturing and transmissivity (Beauheim, 1987a; Saulnier, 1987). Test results were previously interpreted assuming the Culebra Dolomite acts hydraulically as a single-porosity medium. However, recent interpretations show it acts as a double-porosity medium over much of the WIPP site (Beauheim, 1987a, 1987b, 1987c). Hydraulic interference tests are the only source of information on storativity of the Culebra Dolomite. Storativity is a key parameter governing the response of a water-bearing unit to transient stresses and is needed as input to the two-dimensional Culebra Dolomite model (Activity S.4.2.1).

2. Methodology

To provide the required information, existing data from appropriate boreholes will be reinterpreted using analytical techniques incorporating both single and double-porosity formulations. Determinations of which borehole locations in the Culebra Dolomite behave as a single-porosity medium and which behave as a double-porosity medium will be made. These data will be input to the model to support regional scale interpretations.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)

Activity S.4.3.5
CONCEPTUAL HYDROGEOLOGIC MODEL OF THE RUSTLER FORMATION

1. Focus

A conceptual hydrogeologic model is needed to estimate hydrogeologic properties where point data are not available. Models have relied on hydraulic property measurements made at discrete points, but this fails to consider nonnumerical information (LaVenue et al., 1988). Because transmissivity of the Culebra Dolomite is closely related to fracturing in a geologic model, explaining the origin of the fractures and predicting their geographic occurrence is desirable. Establishing a relationship between geology, fractures, and geophysical measurements would enhance the model.

2. Methodology

Cores from the Rustler Formation, the geology of the Air Intake Shaft, nearby outcrops of the Rustler, and geophysical data will be examined to define factors that correlate with transmissivity and define causal relationships. A conceptual model will be developed integrating geologic, hydrologic, and geophysical data to allow predictions of Rustler hydraulic properties or potential for vertical flow paths.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)
Rustler/Salado Formation (1.3.2.3)
Rustler Formation (1.3.2.4)
Rustler/Dewey Lake Red Beds (1.3.2.6)

Activity S.4.3.6
BELL CANYON HYDROLOGIC INFORMATION

1. Focus

Accurate information on Bell Canyon hydrologic properties is needed to define scenarios involving connection of the Bell Canyon with other water-bearing units (Activity S.4.2.3). Some scenarios postulate connecting the Rustler with the Bell Canyon by a drillhole through the repository. Evaluation of the flow and transport properties of the Bell Canyon is needed. The formation has been tested in five boreholes in the past. However, early interpretations, particularly hydraulic gradients, are inconsistent with the two most recent test interpretations (Beauheim et al., 1983; Beauheim, 1986).

2. Methodology

The data from the three early interpretations will be reevaluated to obtain new estimates of transmissivity and hydraulic head in the Bell Canyon. If the data from all five boreholes and the subsequent numerical modeling indicate that transport through the Bell Canyon is a concern in the event of human intrusion, it will be necessary to compile and assess data on the composition of Bell Canyon brines.

3. Information Needs Addressed

Rustler/Salado Formation (1.3.2.3)
Bell Canyon Flow and Geochemistry (1.3.2.9)

Activity S.4.3.7
DEWEY LAKE RED BEDS HYDROLOGY

1. Focus

In the event of any breach involving upward fluid flow from the WIPP facility, contaminated brine might be injected into either saturated or unsaturated portions of the Dewey Lake Red Beds. This activity also supports limited evaluation of Dewey Lake Red Beds hydrology and transport behavior (Activity S.4.2.3). No continuous zone of saturation has been evident in holes drilled at the site. However, there are permeable zones as evidenced by loss of drilling fluid in some holes. A locally significant freshwater aquifer is present along the southern boundary of the WIPP site (Mercer, 1983). Therefore the Dewey Lake Red Beds could, under certain breach scenarios, provide a path to the accessible environment.

2. Methodology

Three phases will be implemented to resolve this concern:

a. All drilling records and borehole histories from WIPP boreholes will be reviewed and assessed for pertinent Dewey Lake Red Beds hydrologic information.

b. A Dewey Lake Red Beds well will be installed to evaluate the nature and properties of the Dewey Lake Red Beds aquifer along the southern WIPP boundary.

c. A brine injection test will be performed at a well that has a known fracture zone in the Dewey Lake Red Beds to assess the transport properties.

3. Information Needs Addressed

Rustler/Salado Formation (1.3.2.3)
Dewey Lake Red Beds (1.3.2.5)
Rustler/Dewey Lake Red Beds (1.3.2.6)
Pressurized Brine Hydrofracturing and Transport (1.3.2.8)

Activity S.4.3.8
SURFACE GEOPHYSICS

1. Focus

Delineation and interpretation of lateral variation in the Rustler Formation as observed in the changes in apparent resistivity across the WIPP site will help determine the flow field and interrelationship of the spatially separated boreholes for use in the two dimensional Culebra Dolomite model (Activity S.4.2.1). Geophysical methods can also assess the effectiveness of borehole plugs and determine the effects of shafts on the Rustler Formation hydrology.

2. Methodology

Geophysical methods proposed are primarily electric or electromagnetic and will measure subsurface resistivities, which is the geophysical property most sensitive to changes in the hydrologic system. Small-scale controlled source audio-magnetotelluric surveys will be conducted as needed. A remotely monitored high-resolution transient electromagnetic array will be designed and installed to monitor the site and large-scale tests.

3. Information Needs Addressed

Culebra Dolomite Member (1.3.2.2)
Dewey Lake Red Beds (1.3.2.5)
Pressurized Brine Hydrofracturing and Transport (1.3.2.8)

Activity S.4.3.9
REGIONAL GEOCHEMICAL STUDIES: SOLUTE CHEMISTRY AND MINERALOGY

1. Focus

Recent interpretation of the geochemical and hydrologic setting of the WIPP facility has emphasized that the overall behavior is transient (Siegel et al., 1988). Evidence suggests a major recharge regime about 10,000 to 20,000 years ago that differs notably from the modern one (Hunter, 1985). Available models are based on a few reliable analyses of the isotopic, chemical, and mineralogic character of the Ochoan system. Reliable predictions of the fate of radionuclides emplaced in the WIPP facility require a better understanding of the histories of rocks and ground water. The resolution of differences among various conceptual models of the evolution of the ground-water system is necessary (e.g., Haug et al., 1987; LaVenue et al., 1988; Chapman, 1988; Lambert, 1988; Siegel et al., 1988). Also, previous studies of Rustler mineralogy have focused on intact core, which tends to bias the sampling. Sampling of less cohesive core is required to characterize mineralogies actually in contact with water recovered during pump tests.

2. Methodology

   a. The mineralogical aspect of this activity will be covered by a review of core descriptions to compare with hydrologic test results. Then mineral assemblages that are probably related to solutes in the fluids will be compiled. Finally, trace-isotope and trace-element studies of key mineral constituents will be performed.

   b. Laboratory analyses of water samples from the Water Quality Sampling Program will be continued to support the solute chemistry program. Additional solutes will be quantified if needed. Data bases on solutes and isotopes will be expanded.

3. Information Needs Addressed

   Recharge (1.3.1.6)
   Extent of Dissolution (1.3.1.7)
   Culebra Dolomite Member (1.3.2.2)

Activity S.4.3.10
REGIONAL GEOCHEMICAL STUDIES: DISSOLUTION

1. Focus

Additional petrographic and isotopic measurements are needed to confidently estimate rock/water ratios and determine the origin of water that interacted with the minerals. The degree and timing of rock/water interactions resulting in evaporate dissolution govern the changes in permeability of water-bearing brittle interbeds in the evaporate section. Therefore, the degree of vertical and lateral water movement within the Rustler and Dewey Lake Red Beds zones that are now carrying or have carried water must be determined. This will allow areas to be identified in which permeabilities may have changed as a result of postdepositional rock/water interactions and evaporite dissolution. It may also determine the time scale over which dissolution has occurred and the mechanisms and pathways of ground water movement that have resulted in changes in rock properties and major and minor solute distribution.

2. Methodology

Ongoing laboratory studies related to evaporate dissolution will be completed. Concurrently, the characterization of gypsiferous rocks in the Ochoan evaporates at and near the WIPP facility with emphasis on characterizing the last major fluids in contact with these rocks will be completed. The rock/water interactions that took place in the Rustler Formation and Dewey Lake Red Beds at the WIPP site and the upper Salado Formation in Nash Draw will be described.

3. Information Needs Addressed

Extent of Dissolution (1.3.1.7)
Culebra Dolomite Member (1.3.2.2)

Activity S.4.3.11
REGIONAL GEOCHEMICAL STUDIES: PALEOCLIMATE

1. Focus

Recent interpretation of the geochemical and hydrologic setting of the WIPP facility has emphasized that the overall behavior is transient. There is evidence of a major recharge regime 10,000 to 20,000 years ago that is notably different from the modern one. The timing and magnitude of extremes in transient behavior of the hydrologic system probably correlate with magnitude and periodicity of geologic events such as climatic fluctuations. To support scenario screening and long-term performance calculations, information on the paleoclimate is needed.

2. Methodology

A bibliography of the paleoclimate will be compiled. Based on mineralogical and element analysis, an estimate of the annual precipitation to the Ochoan/Triassic/Cenozoic hydrologic system during the late Pleistocene in southeastern New Mexico will be determined. Paleoflow patterns in the Dewey Lake Red Beds and Rustler Formation associated with the Pleistocene will be obtained by analyzing faunal remains from Pleistocene deposits and cellulosic material from old trees. Finally, the water budget calculations will be revised and flow models made consistent with wetter climatic conditions for a 10,000-year simulation of WIPP performance under such hydrologic conditions.

3. Information Needs Addressed

Recharge (1.3.1.6)
Extent of Dissolution (1.3.1.7)
Culebra Dolomite Member (1.3.2.2)

2.8 ACTIVITY SCHEDULES

A series of schedules containing key milestones and reports for the performance assessment activities and supporting activities appears on Figures 2-10 through 2-14. These schedules identify the data and models necessary to support the final consequence analysis. The approach to performing the performance assessment analysis is iterative. Available data, and estimates where data are unavailable, will be used to perform a preliminary consequence analysis every six months, with annual reports to be issued until the Draft EPA (40 CFR 191) Compliance Report is completed in June 1993. The final analysis will use the best models and data reasonably achievable at that time. The Final EPA (40 CFR 191) Compliance Report is scheduled to be issued in June 1994.

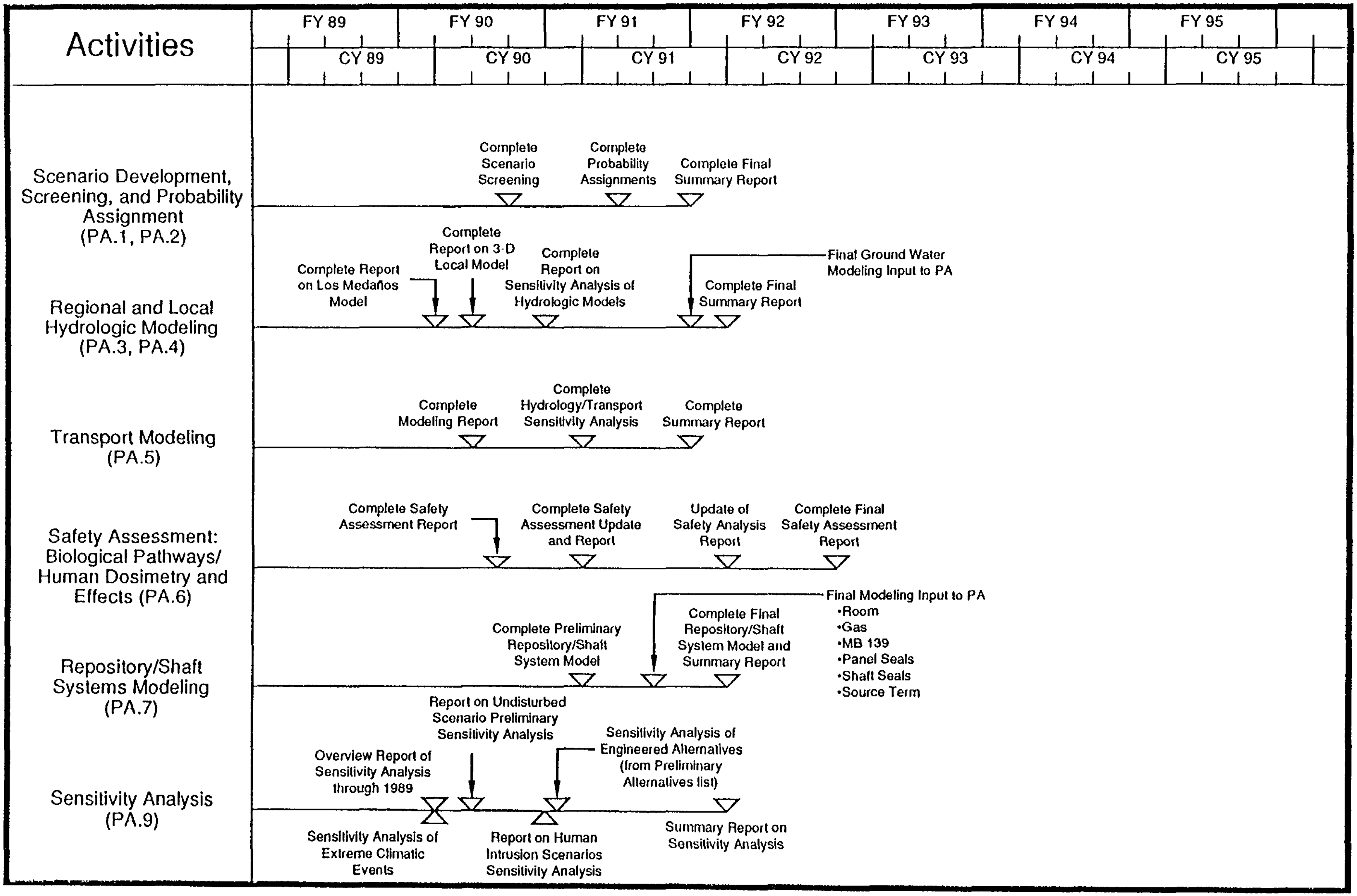


Figure 2-10. Schedule for Performance Assessment Activities

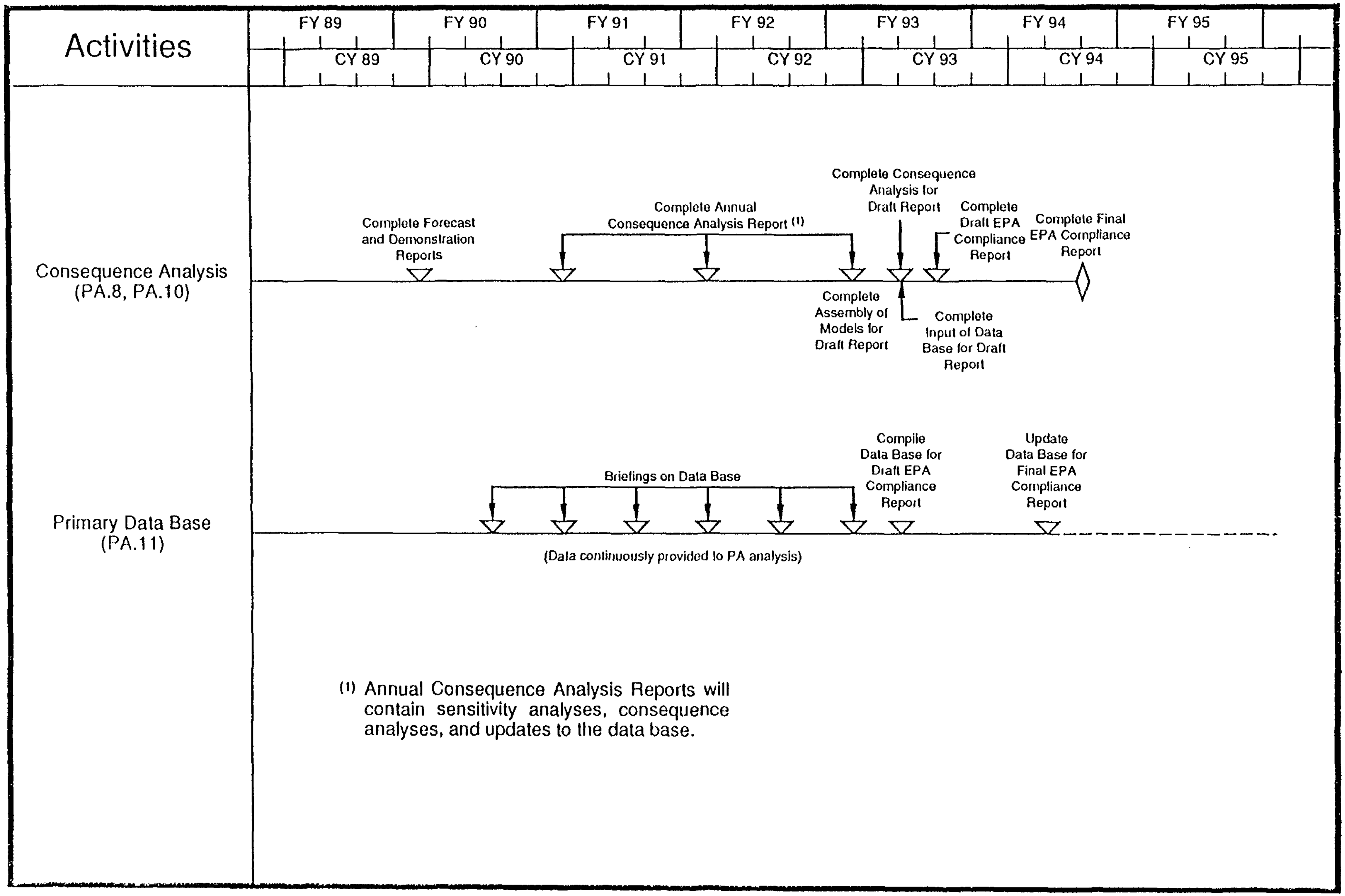


Figure 2-10. Schedule for Performance Assessment Activities (concluded)

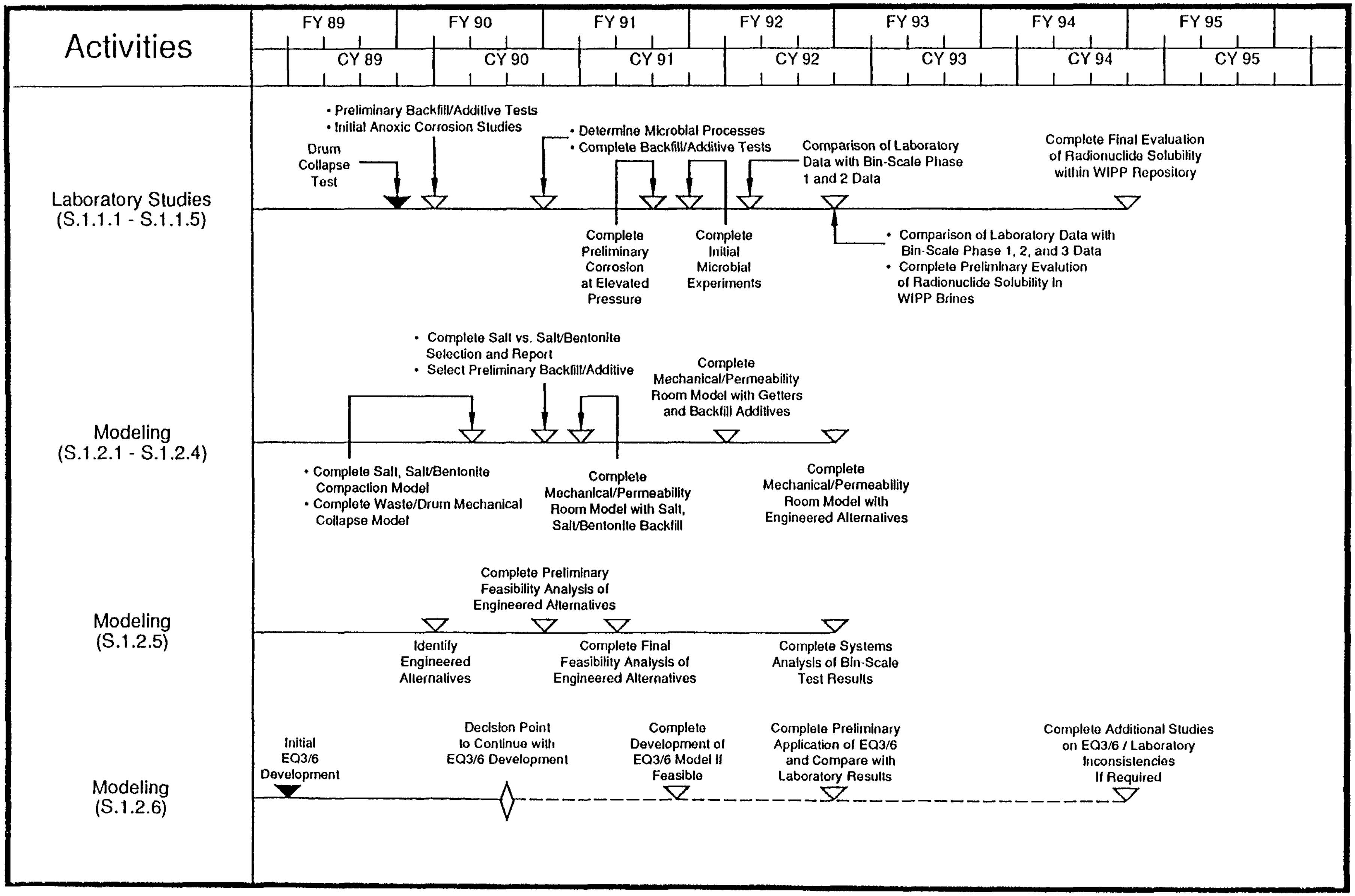


Figure 2-11. Schedule for Disposal Room and Drift System Activities

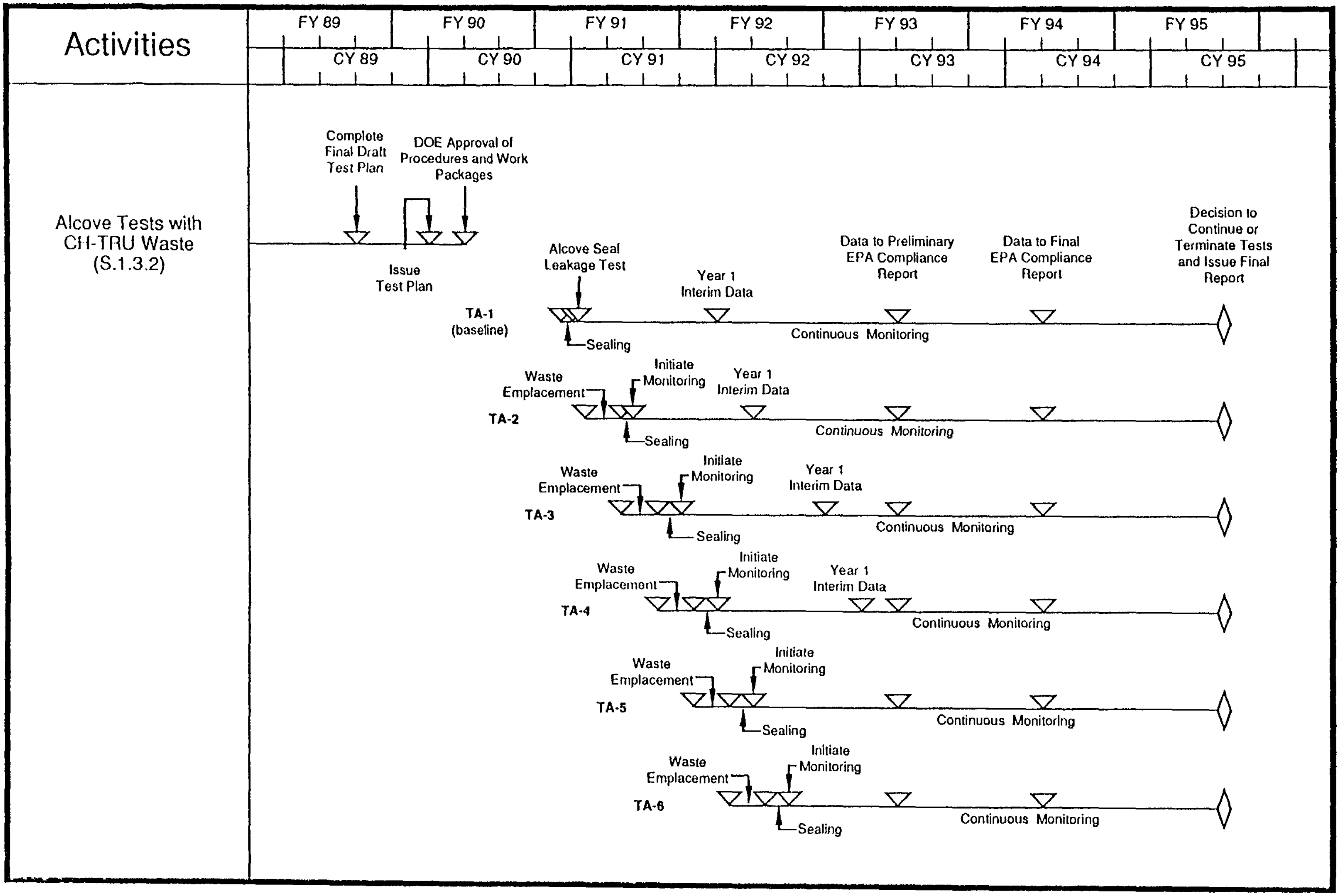


Figure 2-11. Schedule for Disposal Room and Drift System Activities (continued)

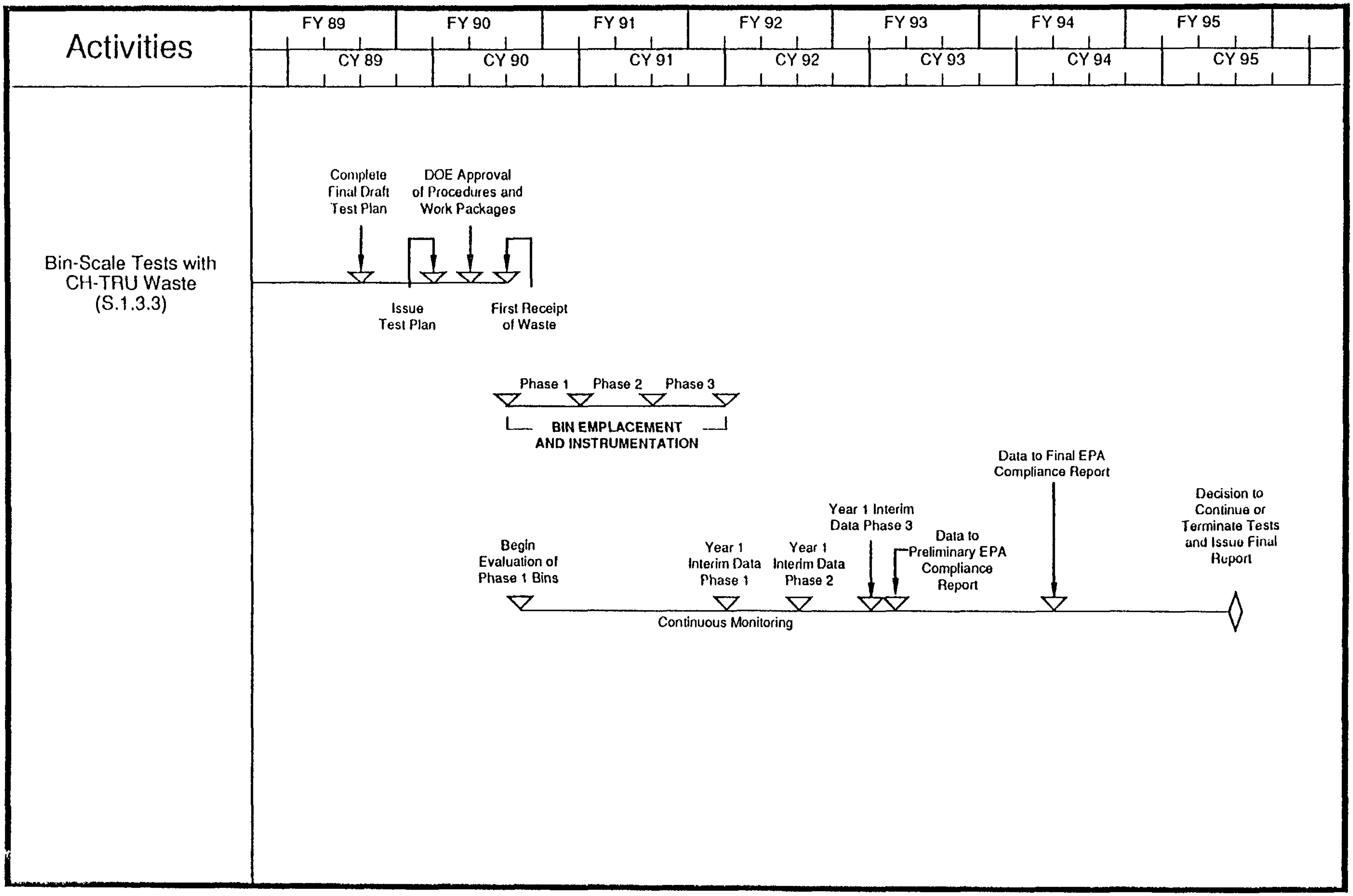


Figure 2-11. Schedule for Disposal Room and Drift System Activities (concluded)

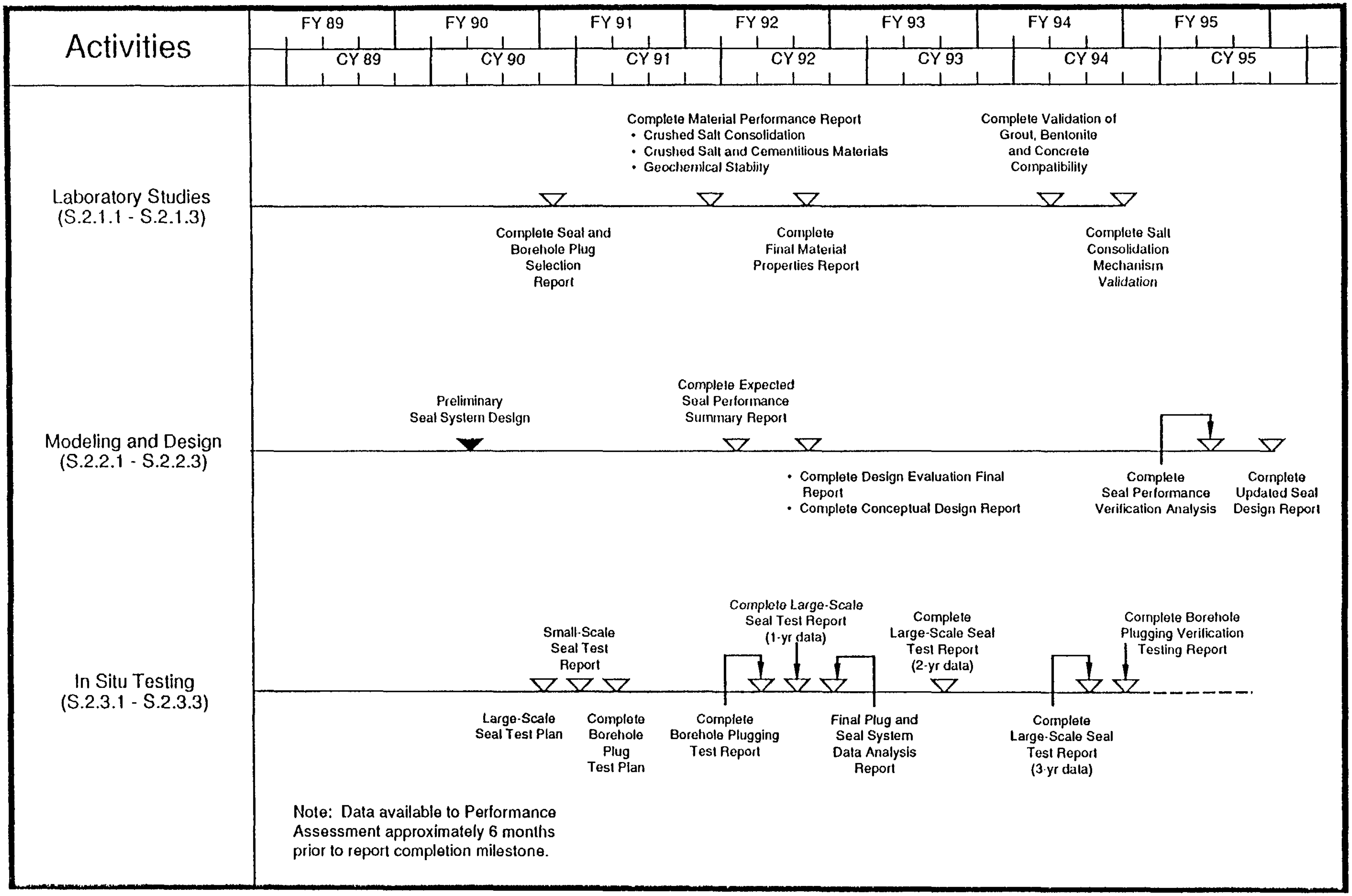


Figure 2-12. Schedule for Sealing System Activities

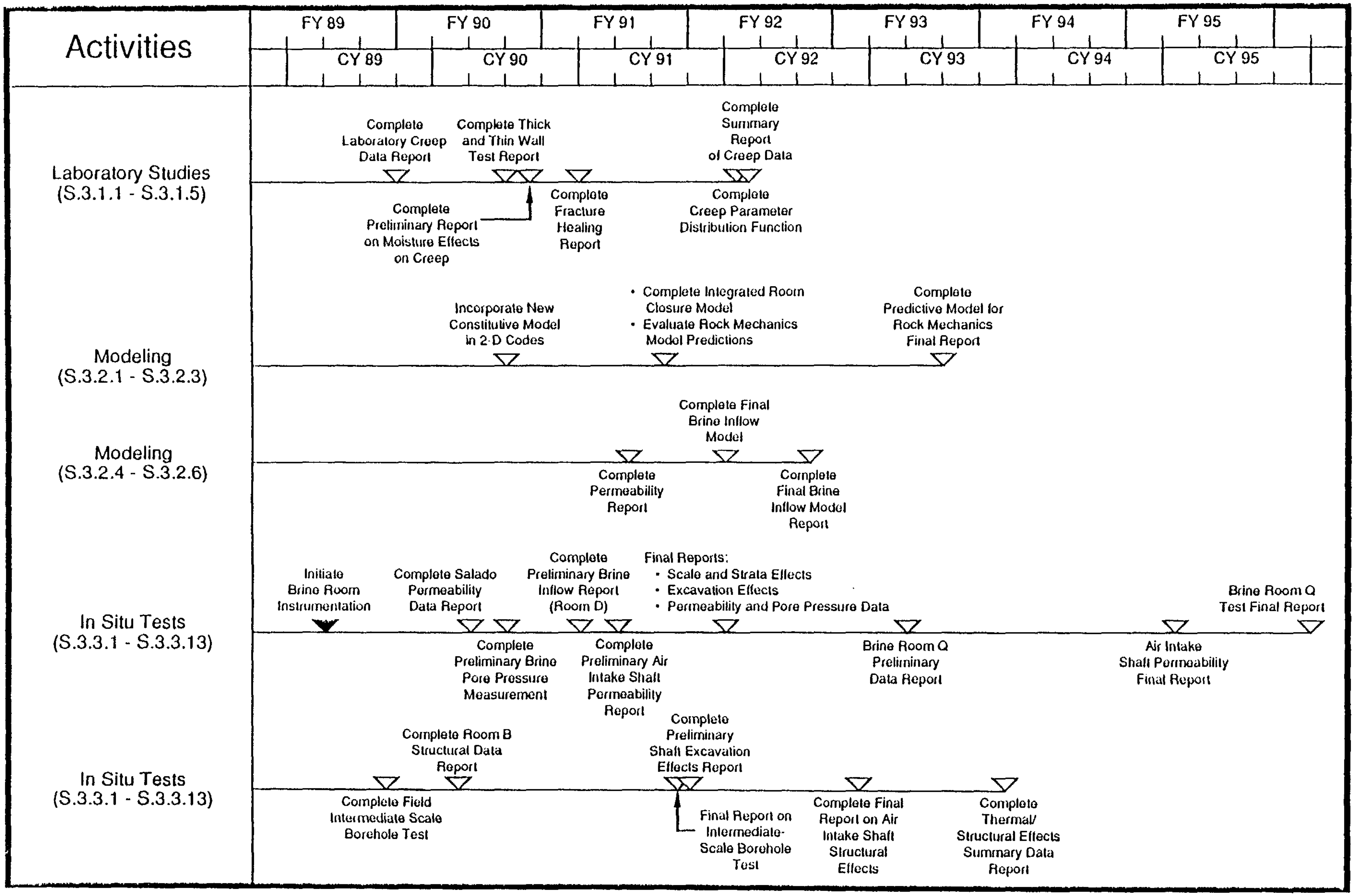


Figure 2-13. Schedule for Salado Formation Structural and Fluid-Flow Behavior Activities

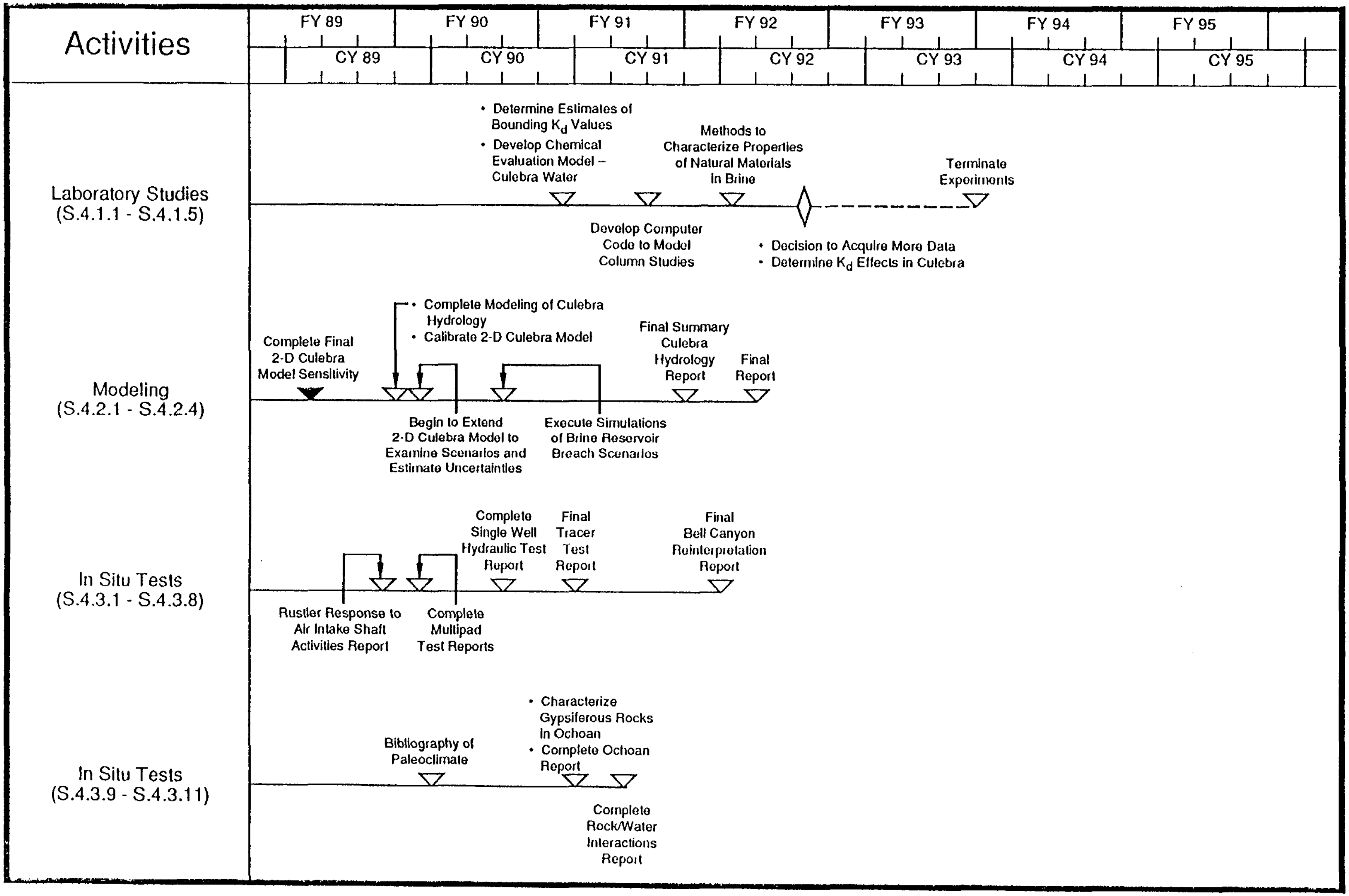


Figure 2-14. Schedule for Non-Salado Formation Hydrology and Nuclide Migration Activities

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APPENDIX A (Revised 11/89)

TESTS WITH CH-TRU AND SIMULATED WASTES

A.0 TESTS WITH CH-TRU AND SIMULATED WASTES

A.1 INTRODUCTION

This appendix has been prepared because of the special interest of the National Academy of Sciences/National Academy of Engineering, the U.S. Environmental Protection Agency (EPA), and the State of New Mexico in those components of the planned experiments during the WIPP test phase that will use radioactive or simulated CH-TRU waste. The multi-part testing program includes (a) laboratory tests with simulated waste; (b) bin-scale tests with CH-TRU waste; (c) alcove tests with CH-TRU waste; and (d) modeling studies to integrate and extrapolate all experimental results to expected repository conditions. The interpreted results will reduce uncertainty in the performance assessment by evaluating predictions of gas generation and of possible interactions between hazardous components of WIPP waste and elements of the WIPP repository.

Laboratory tests will use only simulated (nonradioactive) waste or spiked waste containing a single radionuclide to examine radiolytic effects on waste compaction or on the bioavailability of plastics damaged by alpha radiation. Bin-scale tests will use CH-TRU waste that has been specially prepared to study the synergism between individual waste types, backfill and getter materials, metals, and injected brines. Alcove tests will use unmodified (as-received) CH-TRU waste to obtain information about the initial, operational phase conditions and specially prepared (compacted) CH-TRU waste representative of the longer-term, postoperational phase conditions of a repository. Bin-scale and alcove tests will be conducted underground.

This Appendix describes and justifies the experimental program measurements that will be conducted. It summarizes the necessary procedures, techniques, and operations for acquiring data on TRU waste gas quantities, compositions, generation and consumption rates, and waste material/brine-leachate radiochemical measurements. Extensive variation is expected, resulting from various modes of waste degradation, quantities, and compositions of brine available, and interactions of engineered alternatives with wastes.

A.1.1 <u>BACKGROUND</u>

Containers of TRU waste to be disposed of at the WIPP are a mixture of standard 210-liter (55-gallon) drums and a lesser number of TRU Standard Waste Boxes (SWBs). These containers are filled with wastes from chemical and engineering research, development, and production facilities for U.S. defense programs. The wastes are composed of laboratory hardware such as glassware, ring stands, piping, and other metal structures; cellulosic materials such as towels, tissues, and wiping cloths; protective gloves and clothing; chemicals and inorganic process sludges, many of which are stabilized with cement; various plastics, rubbers, and resins; residues of organic solvents, resulting in possible releases of volatile organic compounds (VOCs); and worn-out or contaminated engineering equipment and tools.

Generally, as soon as waste materials are placed in drums and boxes, they may begin to release gases. In the short term, these gases are generated predominantly by radiolytic degradation of the waste and include hydrogen, oxygen (rapidly depleted in most cases), carbon oxides, and low molecular weight organic compounds (Zerwekh, 1979; Kosiewicz et al., 1979; Kosiewicz, 1981; Molecke, 1979). Radiolysis of water and potentially intruding brines could also generate appreciable quantities of hydrogen (and oxygen) in the postoperational and long-term time periods. Microbial degradation may be of major concern in both the short and long term (Caldwell et al., 1987; Molecke, 1979). Microbially generated gases include carbon dioxide or methane (Caldwell et al., 1987; Molecke, 1979), potentially nitrogen from denitrification of nitrates, and hydrogen sulfide from sulfate-reducing bacteria (Brush and Anderson, 1988a). Anaerobic (anoxic) metal corrosion in the postoperational and long-term periods could also generate large quantities of hydrogen (Brush and Anderson, 1988a; Molecke, 1979). No radioactive gases are generated, with the possible exception of radon, by the decay of transuranic isotopes in the waste.

A.1.2 JUSTIFICATION

A major concern raised by gases released from the TRU waste stored in the WIPP is the possible pressurization of the disposal room during room closure and isolation of the waste. The total amount of gases to be generated and their rates of generation must be quantified, and not merely assumed from possibly inappropriate data. The performance assessment must be able to adequately predict or evaluate at least the following concerns: Will the gas pressure be high enough to retard repository room closure? Will the gas pressure be sufficiently high to fracture the Salado Formation? Will internal gas pressurization affect repository seal performance? Is there a realistic potential for interaction between released VOCs and the backfill or the sealing system? Will sufficient gas be generated to provide a pressurized environment that could release radioactive waste during potential repository post-closure intrusion?

The gases released by stored radioactive wastes and rates of gas generation as a function of time may affect the assessment of radioactive releases from the repository by human intrusion. For a confident evaluation of the effect of the gases on potential release scenarios, a relevant data base that defines the appropriate chemical and microbial reactions and the amounts, compositions, and rates of gases generated is required. Similarly, data are needed on hazardous components (such as VOCs) that may be released from the wastes under repository conditions. These data are needed to quantify impacts on the performance of the repository or meet monitoring requirements of 40 CFR 268, the Resource Conservation and Recovery Act (RCRA).

The present form of the EPA Standard for radioactive waste disposal, 40 CFR 191, requires that repository performance be predicted for 1,000 years for individual protection and for 10,000 years for containment. For these very long time periods, experimental testing in real time cannot be used to demonstrate performance. The Standard suggests that a probabilistic, predictive, mathematical approach be used, in which models or model segments are used to simulate, over time, the important processes identified by field exploratory research. Data also must be acquired for input to the probabilistic predictive models. Several kinds of data on the potential in situ behavior of CH-TRU waste are needed for WIPP performance assessment modeling and analyses: (1) gas speciation, generation, and depletion rates as a function of time, including the impacts of several other waste-condition parameters such as degree of compaction and state of saturation; (2) source term definition of leached or mobilized chemical and radiochemical species, as interpreted from both the bin-scale test internal gaseous atmosphere and potential chelating or complexing agent in leachate brines, either initially present in the actual wastes or formed by various degradation mechanisms; and (3) systems interactions and synergisms occurring between all materials and mechanisms within the TRU waste container. The impacts of radiolysis, microbial degradation, and chemical corrosion on gas generation can be adequately analyzed and evaluated under known, controlled conditions in these planned radioactive and simulated TRU waste tests. Their extrapolation to full repository pressure and fluid-flow behavior will, however, continue to require numerical extrapolation of experimental results.

The analyzed brine leachate samples from individual bin-scale tests may not provide definitive source terms, but they will provide realistic (not assumed) TRU species concentrations as influenced by organic ligands or other chelating agents. These concentrations can be affected by actual waste materials and TRU interactions with leached organic ligands or chelates and other gas atmosphere and chemical components, which could appreciably change solution pH and Eh. Fewer assumptions will, therefore, have to be made concerning species solubilities or solubility limits in subsequent performance assessment calculations.

A.1.3 RATIONALE

The gas and water contents of TRU waste disposal rooms could affect long-term performance, especially in the event of human intrusion. Current estimates of the rates of gas production by TRU waste are based on laboratory studies of processes such as radiolysis, microbial activity, corrosion, and thermal degradation (Zerwekh, 1979; Kosiewicz et al., 1979; Kosiewicz, 1980, 1981; Caldwell et al., 1987; Molecke, 1979) and field studies of headspace gases in drums (Clements and Kudera, 1985). The extreme heterogeneity of CH-TRU waste resulting from the variety of waste streams exacerbates the difficulty of getting gas production data representative of the total waste mix. To do so requires large numbers of experiments on multiple types of TRU wastes, conducted under closely controlled conditions.

In the past, gas generation did not seem critical to considerations of the WIPP's long-term performance. Calculations of the diffusive transport of gas out of the repository and into the surrounding Salado Formation (DOE, 1980; SNL, 1979) implied that even if the high gas production rates estimated as upper limits by Molecke (1979) were applicable, the permeability of the surrounding rock would be high enough to allow gas to escape without a significant increase in repository pressure. Recent, more definitive, far-field permeability measurements (Tyler et al., 1988), however, imply that high gas production rates may pressurize the repository. Thus, it has become necessary to resolve the differences between estimates of gas production rates to establish a realistic range of gas production rates in the WIPP environment.

Recently, Brush and Anderson (1988a) calculated that processes such as drum corrosion, microbial decomposition of cellulosic materials, and reactions between drum corrosion products and microbially generated gases could affect the gas budget of the repository. These processes could consume or produce quantities of water similar to quantities of brine recently predicted to seep into the repository from the Salado Formation (Activities S.3.3.6 through S.3.3.13).

Laboratory, bin-scale, and alcove tests with CH-TRU and simulated wastes are thus necessary to acquire data for predicting the long-term gas and water content of WIPP disposal rooms and to assess their impact on repository performance. It has become evident during the past year that more data on gas evolution rates are critical to understanding and addressing the behavior and ultimate state of the repository. The TRU waste experiments described in this Appendix will provide many of the data required to develop the understanding and an acceptable level of confidence in predictions of performance and in comparisons with the EPA Standard, 40 CFR 191, Subpart B.

A.1.4 APPROACH

The assessment of gas issues must consider three elements: gas production, gas consumption, and gas transport. Gas is produced by radiolytic, chemical, and biological reactions between the waste, waste containers, engineered backfill, brine, and salt. Gas consumption, normally controlled by radiolysis, microbial degradation, and corrosion, can presumably be increased by including gas getters in the backfill component materials. Gas transport depends on the ability of the formation to accept the gas and allow it to disperse. At WIPP, waste will be emplaced in a layered sequence of Salado evaporites consisting of pure to impure halite, including numerous marker beds of anhydrite, clay, and polyhalitic halite. The primary parameter controlling gas transport is gas permeability of the geologic formation, which differs for different gases and stratigraphic layers. The issue of gas transport and the response of the repository to elevated internal gas pressures can be and is being studied without waste, but gas production and consumption are strong functions of the waste itself.

The laboratory experiments will provide detailed kinetic data on individual mechanisms of concern and will provide a major focus for numerical extrapolation of experimental results. However, to accurately measure net gas production and consumption under realistic conditions, actual radioactive wastes must be used. Thus, data needed for the performance assessment models can only be obtained from the combination of laboratory tests (small-scale, simulated waste) (Brush, 1989; Zerwekh, 1979; Kosiewicz et al., 1979; Kosiewicz, 1980, 1981; Caldwell et al., 1987; Molecke, 1979), intermediate, bin-scale tests (Molecke, 1989a), and large, alcove (field) tests (Molecke, 1989b). Data from these three experimental programs, when coupled with model development, will be used to assess the importance of gas in the repository, including the interactions of gas, brine, and structural behavior. The strong interrelationships among these experimental programs and the perceived benefits and disadvantages of each are summarized below.

Ongoing laboratory tests (Brush, 1989), in combination with earlier laboratory test results (Zerwekh, 1979; Kosiewicz et al., 1979; Kosiewicz, 1980, 1981;

Caldwell et al., 1987; Molecke, 1979), will provide a large proportion of the early data. These tests will provide detailed information on each degradation mode of gas generation and on the efficacy for minimizing gas production of various getter materials, waste form modifications, and other engineered alternatives to be developed.

Laboratory tests have the following advantages:

1. They are easier than field tests to set up and control experimentally.

2. They can incorporate the effects of more test variables and analyze the direct impacts of each variable separately on gas production.

3. They can evaluate speciation and solubilities of plutonium, americium, uranium, and thorium as a function of Eh and pH, including the effects of individual getters on Eh and pH.

4. They can specifically address the biodegradation of VOCs, of concern in 40 CFR 268.

5. They can be safely conducted at high pressures, similar to repository lithostatic pressures (15 MPa or higher). Because of test safety concerns and constraints on the bin-scale and alcove test programs, only the laboratory testing program can provide the gas high pressure results needed.

Laboratory tests, however, also have the following significant disadvantages:

1. They use simulated, rather than actual, TRU waste.

2. They are performed on a very small scale relative to a repository, making scaling factor effects a significant unknown.

3. They do not address interactions between waste types.

4. They do not contain the same microbial inoculants as found in actual TRU wastes.

5. The impacts of radiolysis on the anaerobic corrosion of steels cannot be addressed.

6. Total synergistic reactions among all real-waste components are not present.

7. The laboratory test system is simple and may not adequately represent the repository for a thoroughly credible performance assessment.

The bin-scale tests are similar in scope to the laboratory tests, examine most of the parameters of the laboratory tests, provide data on gas generation and getter effectiveness, and help evaluate and extend the results of the laboratory tests to more complex geometries and settings. The bin-scale tests may be viewed as larger-scale laboratory experiments, except that they have the following advantages:

1. They incorporate actual radioactive TRU waste, including minor chemical components, organic compounds and solvents, and microbial contaminants that could affect overall gas generation and source term radiochemistry.

2. There are few test simulations or required assumptions.

3. All test components, waste forms, contaminants, and possibly engineered alternative materials are interacting in a synergistic environment, in which various modes of gas generation occur simultaneously.

4. The larger scale of the test bins, incorporating about 6 drum-volumes of wastes each, helps smooth out the known inhomogeneities among similar waste types.

5. The total test matrix can be expanded as necessary to incorporate new waste forms, backfill and getter materials, and engineered alternatives as they are developed and are ready for testing.

6. These tests can provide data rapidly compared with alcove tests, consistent with present WIPP performance assessment schedules.

The bin-scale test program has the following disadvantages:

1. Tests cannot be conducted at high gas pressures.

2. Not all repository environmental effects can be incorporated, as they can be in alcove tests.

3. The performance of bin-scale tests at WIPP is linked to first receipt of waste.

4. Tests can only examine limited interactions between waste types.

The in situ alcove tests will be conducted under credible, expected-case repository conditions. The major advantages of the alcove tests follow:

1. Tests will provide "real world" data, with few simulations or restraints that could potentially bias the end results.

2. Only alcove tests incorporate the environmental, possibly synergistic effects of the repository itself (e.g., gases and fluids released from the host rock, mine geochemistry and biochemistry) on waste degradation rates and modes.

3. Assessments will determine the gas generation rates for the times of interest and will incorporate gas consumption or transportation from the disposal room through the rock or fractures therein.

4. No significant scaling effects result from the size of the test alcoves (approximately 1/4 full scale).

5. Many waste forms are mixed together in the same test alcove, as would be the case in an operating repository.

The major disadvantages of the alcove tests follow:

1. Tests cannot be performed at high gas pressures because of safety concerns.

2. The number of test alcoves available is small, significantly limiting the number of test variables and test replicates that can be incorporated.

3. The large volume of each test alcove, plus the initial trapped gas (air or nitrogen), decreases the analytical sensitivity for gases of interest being produced: small changes in the quantity of produced gases may be masked.

4. The expected rates of production for individual gases, and changes in those rates, may not be clearly evident for an appreciable period of time compared with gases generated and analyzed in the smaller test bins.

The added degrees of experimental control, assumed increased sensitivity and selectivity for gas analyses, and the increased number of test conditions for variables to be used in bin-scale tests relative to alcove tests allows the interpretation of obtained data to be simpler and more straightforward than that from the alcove tests. Thus, the bin-scale tests provide a technically more satisfying and rapid means of obtaining data.

Collecting data from any of these tests is not simply a monitoring or confirmatory activity. In almost all cases, measures are being taken to ensure that data are readily available or will address time scales of interest other than the operational phase. Data must be used for both analytical and predictive performance assessment modeling and for comparison with smaller-scale laboratory data on simulated wastes. The combined suite of CH-TRU waste test programs--laboratory, bin-scale, and alcove--is required to provide the full spectrum of information needed for the WIPP performance assessment program, and these three experimental activities must be linked with both geochemical modeling and studies of the response of WIPP to elevated gas pressures, should these be generated. Each test program has significant advantages and disadvantages. None of the three test programs alone can credibly produce the required information.

The laboratory tests (Brush, 1989; Bertram-Howery and Hunter, 1989) were initiated in FY89 and will be conducted in parellel with the WIPP bin-scale and in situ alcove (Molecke, 1989b) tests, both of which will begin in FY90. These parellel test programs will proceed concurrently and will be sequenced to permit the early laboratory results to have some impact on the configuration of the bin-scale tests, and vice versa. For example, backfill getter additives to be evaluated in laboratory tests for gas and brine sorption capability would be selected and evaluated by the end of FY90 (Lappin, 1989a), then subsequently evaluated for in situ efficacy in Phases 2 and 3 of the bin-scale tests (to be described below). Also, preliminary brine-leachate results from the bin-scale tests could be used to help focus laboratory evaluations of radionuclide chemistry into specific ranges of test conditions as quickly as possible (Lappin, 1989a). Initial results from both the laboratory and bin-scale tests could be used to help redefine the starting test parameters of the alcove tests on an alcove by alcove basis, assuming that the wastes and other test materials had not already been loaded, the alcove sealed (from access), and testing in that specific alcove initiated. Results from the alcove tests are not currently expected to provide feedback to the laboratory and bin-scale tests because of their later schedule for sequencing and emplacement--with the possible exception of later contingency additions to Phase 3 of the bin-scale tests.

A.2 LABORATORY TESTS OF REPOSITORY AND RADIONUCLIDE CHEMISTRY

A.2.1 RATIONALE

Laboratory studies are planned to develop a mechanistic understanding of repository gas and radionuclide chemistry. Laboratory studies can quantify the effects of significant processes under conditions that isolate each process from the complex effects of other processes, yet are nevertheless realistic, and they can determine the effects of variations in repository conditions on these processes. To minimize the number of variables in the laboratory studies, standard brines have been developed for use in microbial, corrosion, radiolysis, and backfill experiments. The standard brines represent natural compositions found in the Salado and Castile Formations and synthetic brines developed to simulate fluids equilibrated with potassium and magnesium bearing minerals in potash facies overlying WIPP (Molecke, 1983; Brush, 1989; Lappin et al., 1989).

Several processes could affect the repository gas and water budgets. The air trapped in WIPP disposal rooms when they are filled and sealed will comprise mainly nitrogen and oxygen. The Salado Formation will release brine and will initially release gas, mostly nitrogen, possibly with some methane. Eventually, the Salado Formation might serve as a sink for all gases, except perhaps nitrogen. Corrosion, either oxic or anoxic, of drums, metal boxes, and metallic constituents of the waste (hereinafter called "metals") will consume significant quantities of water and (in the case of anoxic corrosion) will produce significant quantities of hydrogen in the presence of excess brine. Microbial activity, either aerobic or anaerobic, halophilic, halotolerant, or nonhalophilic, will oxidize cellulosic materials and perhaps other materials in the waste, such as plastics and rubbers. Microbial degradation of the waste will produce carbon dioxide in potentially large amounts, as well as potentially large quantities of other gases under certain conditions. These other gases could include hydrogen sulfide, methane, and nitrogen. Microbial activity could also affect the water budget of the repository, but the net effect is unclear at present. Hydrogen gas may be removed by microbial sulfate reduction, and hydrogen sulfide may be removed by reacting with iron, iron-based alloys, or their corrosion products, to form pyrite. The formation of pyrite, however, will release the hydrogen consumed during sulfate reduction and perhaps produce additional hydrogen, as well as release any water consumed during oxic or anoxic corrosion. Radiolysis of brine, cellulosics, plastics, and rubbers will consume water and produce carbon dioxide, carbon monoxide, hydrogen, and oxygen. Radiolysis could also increase the microbial gas production potential by transforming plastics and rubbers into more biodegradable materials. Brush and Anderson (1988a, 1988b, 1988c) have described these reactions in detail.

Brush and Anderson (1988a, 1988c) proposed several backfill additives to remove or prevent the production of gas. Calcium carbonate, calcium oxide, potassium hydroxide, and sodium hydroxide might remove carbon dioxide. Calcium oxide might also remove water. The addition of manganese dioxide, an electron acceptor, might prevent microbial sulfate reduction; the concomitant production of hydrogen sulfide; the reaction of hydrogen sulfide with iron, iron-based alloys, and their corrosion products to form pyrite; and the concomitant production of hydrogen. Copper sulfate, an oxidant, might allow corrosion of metals without producing hydrogen. It is unclear at present, however, whether these proposed backfill additives will be effective, whether they will affect other aspects of repository chemistry deleteriously, or whether they will inhibit the closure of WIPP disposal rooms by increasing the strength of the materials in the rooms.

Reactions between any brine present in the WIPP disposal rooms and backfill additives and metals could change the Eh (oxidation potential) and pH of the brine significantly, especially if caustic materials are in the backfill as gas getters. Microbial activity and corrosion of metals would decrease the Eh. However, radiolytic production of oxygen or peroxides would tend to increase Eh. Microbial activity, for example, could decrease the Eh to values characteristic of denitrification or nitrate reduction, the reduction of manganese(IV) oxides or hydroxides, the reduction of iron(III) oxides or hydroxides, or even sulfate reduction. (Numerical values of Eh for any of these processes depend on pH, which cannot be predicted yet.) Microbial production of carbon dioxide could decrease the pH of the brine to acidic values. Reactions between brine and the cements used in seal and to grout some of the drums could increase the pH to basic values. Reactions between brine and three backfill additives proposed for the removal of carbon dioxide (calcium oxide, potassium hydroxide, and sodium hydroxide) could increase the pH to very basic values.

Because the possible ranges of Eh and pH for any brine after the reactions described above are so wide, the speciation, solubilities, and sorptive behavior of the important radionuclides in TRU waste could vary significantly. Unfortunately, there are no thermodynamic data for the actinide elements in solutions with ionic strengths of WIPP brines (see Activity S.1.1.4). Laboratory studies of radionuclide chemistry will therefore be necessary over a wide variety of conditions, but will be focused on conditions under which high solubility is thought to be possible.

In support of laboratory studies, solubility and speciation will be modeled with the EQ3NR/EQ6 geochemical code (Wolery, 1979, 1983; Wolery et al., 1984). Modeling studies could reduce the number of experiments required to quantify repository gas production. Presently, modeling of brines with the Pitzer equations (Pitzer, 1973; Pitzer and Kim, 1974) is limited to the system Ca^{+2}, K^{+}, Mg^{+2}, Na^{+}, Cl^{-}, HCO^{-3}, SO_4^{-2}, and H_2O. Therefore, additional development of the EQ3NR/EQ6 code will take place at Lawrence Livermore National Laboratory to address chemical reactions between brine and clay minerals and between brines and radionuclides present in the waste. This effort will be focused toward experiments to determine ion interaction parameters for Al^{+3}, Cu^{+2}, Fe^{+3}, Mn^{+2}, Mn^{+4}, and Si^{+4}, and the development of an activity coefficient model to describe hydration theory (Stokes and Robinson, 1948), which could be successfully applied to the modeling of radionuclides in brine.

A.2.2 OBJECTIVES

1. Quantify the production of hydrogen by anoxic corrosion of metals under various conditions, including brine saturated and humid conditions at both ambient and elevated gas pressures.

2. Quantify the potential for and rates and effects of microbial degradation of nonradioactive constituents of TRU waste on the gas and water budgets of WIPP disposal rooms, the Eh and pH of any brine present, and the chemical behavior of radionuclides.

3. Determine the effects of radiolysis on the bioavailability of plastics and rubbers.

4. Quantify the chemical effectiveness of proposed backfill additives to remove gas or prevent its production and the chemical effects of these same additives on repository brine geochemistry (including the rate of anoxic corrosion).

5. Quantify the chemical behavior of important radionuclides in TRU waste in likely WIPP brines under conditions in which high radionuclide solubility is expected.

A.2.3 DESCRIPTION

The laboratory studies of repository and radionuclide chemistry are briefly discussed below. Much greater detail is available in Brush (1989).

Laboratory Studies of Microbial Degradation of Nonradioactive Simulated Waste

Microbial degradation of nonradioactive constituents of the waste will produce potentially large quantities of gas. Based on an extensive literature review and experimental program, Molecke (1979) concluded that the "most probable overall average" gas production rate for TRU waste under expected WIPP conditions is 0.3 to 1.4 moles/drum/year and that microbial degradation will be the most important component of this gas production rate. Sandia National Laboratories (1979) concluded that the microbial gas production potential of an average TRU waste drum is 2,000 moles. Although Brush and Anderson (1989) estimated a lower microbial gas production potential of 589 moles/drum, they found no reason to lower Molecke's (1979) estimate of the microbial gas production rate. Microbial degradation is therefore one of the two processes of most concern from the standpoint of the repository gas budget. The other process, anoxic corrosion of metals, is discussed below.

The experimental program directed by Molecke (1979) yielded valuable data on the overall microbial gas production rate under expected repository conditions. Subsequently, however, an increased awareness by geochemists of the role of microorganisms in mediating (controlling or promoting) diagenetic oxidation-reduction (redox) reactions has led to the development of a conceptual model of the effects of microbial activity on low-temperature geochemical systems. Froelich et al. (1979) and Berner (1980) have described this model in detail; Brush and Anderson (1988a) applied it to the microbial degradation of TRU waste in WIPP disposal rooms. In predicting the long-term performance of the WIPP disposal system, the most important results obtained from this model have been: (1) a method for identifying microbial processes that could affect the gas and water budgets of the repository significantly; and (2) the understanding that microbially mediated reactions can determine the Eh and pH of low-temperature geochemical systems, and hence the speciation, solubilities, and sorptive behavior of radionuclides in these systems (see for example, Sholkovitz et al., 1983).

Based on a review by the WIPP Performance Assessment Source Term Group (Brush, 1989) the following anaerobic microbial processes (listed in general order of decreasing oxidation state) could significantly affect WIPP repository and radionuclide chemistry: (1) denitrification (the use of nitrate as an electron acceptor, with concomitant production of carbon dioxide and nitrogen) under saline conditions; (2) sulfate reduction (the use of sulfate as an electron acceptor, with concomitant production of carbon dioxide and hydrogen sulfide) under saline conditions; and (3) fermentation and methanogenesis (the consumption of carbon dioxide and hydrogen, or acetate, with concomitant production of methane) under both asaline conditions (prior to rupture of drums and boxes and resaturation of the repository with brine) and saline conditions. Aerobic respiration, reduction of manganese(IV) oxides and hydroxides, and reduction of iron(III) oxides and hydroxides will not be important in the repository.

The laboratory microbiological studies have several objectives: (1) to determine whether the potentially significant processes identified above actually occur under saline conditions or, in the case of fermentation and methanogenesis, under asaline conditions; (2) to determine whether the microorganisms responsible for any significant processes are likely to survive long enough to affect the long-term performance of the WIPP disposal system; (3) to quantify under realistic (not overtest) conditions the effects on the repository gas and water budgets of those significant microbial processes that actually occur; and (4) to quantify under realistic conditions the effects of those processes on the chemical behavior of important radionuclides in waste.

<u>Laboratory Studies of Radiolysis</u>

Molecke (1979) concluded from simulated waste experiments that the rate of radiolytic gas production by most TRU wastes under expected WIPP conditions will be much lower than either the potential long-term microbial gas production or the production of hydrogen by anoxic corrosion of metals estimated by Brush and Anderson (1989) assuming excess brine. However, radiolytic gas production from TRU-contaminated inorganic process sludges, which contain a large percentage of bound water, could be appreciable during both short- and long-term waste isolation.

Because the Rocky Flats Plant presently plans to compact newly generated waste, a laboratory study of the effects of compaction on the radiolytic gas production rate is planned.

Estimates of the total gas production potential of TRU waste are sensitive to assumptions about the extent to which microorganisms will degrade cellulosic materials, plastics, and rubbers in the WIPP inventory. Brush and Anderson (1989) calculated a total gas production potential of 1,480 moles/drum (589 moles/drum from microbial activity, 894 moles/drum from anoxic corrosion) by assuming that microorganisms convert 100 percent of the cellulosics and 50 percent of the rubbers but none of the plastics in the WIPP inventory to gas. Their estimate of the microbial component of the gas production potential would have been much higher if they had assumed that microorganisms will degrade plastics significantly. In fact, conversion of all the plastics could increase the <u>total</u> gas production potential to a value close to that estimated by Sandia National Laboratories (1979), 2,000 moles/drum.

Microorganisms will almost certainly consume cellulosic materials in preference to plastics and rubbers. Radiolysis of plastics and rubbers, however, could transform them into more bioavailable materials. A laboratory study of the effects of radiolysis on the bioavailability of plastics and rubbers is therefore necessary to determine the gas production potential of TRU waste. Radiolysis may also produce oxidants, such as oxygen and hydrogen peroxide, that may affect the oxidation state of the repository and hence the ability of anaerobic microbes to survive.

The detailed objectives of the laboratory radiolysis studies are (a) to document the present best estimate of radiolytic gas generation under expected repository conditions; (b) to examine the possible effects of waste compaction on radiolytic gas generation under saturated and dry conditions; and (c) to determine whether radiolysis of plastics and rubbers might increase the gas-generation potential from microbial activity.

<u>Laboratory Studies of Anoxic Corrosion</u>

Assuming that anaerobic conditions dominate and that brine saturation is maintained, Brush and Anderson (1989) used recent estimates of the quantities of metallic constituents in the WIPP inventory to calculate that anoxic corrosion of metals would produce 1.70 moles of hydrogen/drum/year, and that the hydrogen-production potential from anoxic corrosion would be 894 moles/drum. Anoxic corrosion is thus the process of greatest concern from the standpoint of the gas budget of the repository, assuming that excess brine will be available for corrosion reactions and that the overall repository environment is sufficiently anaerobic.

Brush and Anderson (1989) based their estimate of the hydrogen production rate on anoxic corrosion data from Molecke (1979) and Haberman and Frydrych (1988). Molecke (1979) reviewed data from a laboratory study of the corrosion of 1018 mild steel (the same alloy used for the drums) in sodium chloride-saturated brine at 25°C. Haberman and Frydrych (1988) studied corrosion of A216 Grade WCA mild steel in Permian Basin brines at 90, 150, and 250°C; Brush and Anderson (1988a) extrapolated these data to the expected WIPP temperature of about 30°C and the lower magnesium concentrations of intergranular brines from the Salado Formation.

Although anoxic corrosion will almost certainly produce large quantities of hydrogen if magnesium-bearing brine saturates the repository, it is unclear whether anoxic corrosion will occur in the presence of water vapor or of water previously absorbed by bentonite in contact with metals. Additional laboratory studies are necessary (1) to measure anoxic corrosion rates for relevant iron and steel alloys in likely WIPP brines at 30°C, if possible; (2) to determine whether anoxic corrosion occurs using water vapor and, if so, to measure its rate; (3) to determine whether anoxic corrosion occurs using water absorbed by bentonite and, if so, to measure its rate; (4) to determine whether anoxic corrosion of other metals in the WIPP inventory occurs and, if so, to measure corrosion rates for these metals; and (5) determine whether the high pH values expected to result from adding caustic materials to the backfill as gas getters might impede anoxic corrosion.

Laboratory Studies of Proposed Backfill Additives

Carbon dioxide will probably be the most abundant microbially produced gas under most conditions. Brush and Anderson (1988a) proposed the use of four backfill additives to remove carbon dioxide from WIPP disposal rooms: calcium carbonate, calcium oxide (anhydrous or hydrated), potassium hydroxide, and sodium hydroxide. Calcium carbonate would remove carbon dioxide only if brine were present; calcium oxide, potassium hydroxide, and sodium hydroxide would remove carbon dioxide in the absence of brine. Brush and Anderson (1988a) calculated that about 87,000 kg of potassium hydroxide or 62,000 kg of sodium hydroxide per room would be required to remove all microbially produced carbon dioxide. They did not calculate the required quantities of calcium carbonate or calcium oxide because the stoichiometry of carbon dioxide uptake by these compounds has not been defined for expected WIPP conditions. Because the quantity of any backfill additive needed to remove carbon dioxide depends critically on how much of the microbially produced gas is in fact carbon dioxide, which is now unknown, the required quantities of any of these backfill additives cannot yet be estimated, unless it is assumed that all of the gas is carbon dioxide. Because the required quantities of these backfill additives have not been calculated at this time, the pH of brine after it reacts with these compounds or their carbon dioxide-bearing reaction products cannot be predicted yet, but it could increase to extremely basic values. This could in turn either hasten or retard anoxic corrosion of metals, as well as increase the concentrations of dissolved radionuclides by forming carbonate complexes. A potential compensating factor might be removal of gaseous CO_2 by precipitating such phases as magnesite ($MgCO_3$) if enough brine is present.

Adding manganese dioxide, an electron acceptor, to the backfill might prevent (1) microbial sulfate reduction and concomitant production of hydrogen sulfide; and (2) back-reaction of hydrogen sulfide with metals and their corrosion products to form pyrite and concomitant production of hydrogen. The use of manganese dioxide as a backfill additive, however, has three potential limitations: (1) it must be demonstrated that there are halophilic or halotolerant microorganisms that can use manganese dioxide as an electron acceptor under expected WIPP conditions; (2) it must be demonstrated that these microorganisms would survive in the repository until conditions conducive to manganese(IV) reduction occurred, and throughout the period during which manganese(IV) reduction would be required; and (3) manganese dioxide is very insoluble and thus might not migrate through any brine fast enough to prevent significant sulfate reduction in isolated locations in WIPP disposal rooms.

Finally, adding copper sulfate, an oxidant, to the backfill might allow metals to corrode without producing hydrogen. However, copper sulfate would only be effective if brine were present; similarly, anoxic corrosion might not occur in the absence of brine. Brush and Anderson (1989) estimated that 878,000 kg of copper sulfate per room would be required to corrode all of the metals without producing hydrogen.

The objectives of laboratory studies of proposed backfill additives are (1) to determine which of the several gases expected under repository conditions (CO_2, CH_4, H_2S, H_2, N_2, NO_x) can be removed or prevented by these compounds; (2) to quantify their effects on repository chemistry; and (3) to examine whether there are any potentially deleterious interactions between VOCs of interest and any proposed backfill additives. Studies of possible effects of proposed backfill additives on the closure of WIPP disposal rooms are described in Activity S.1.1.1.

Laboratory Studies of Radionuclide Chemistry

Predicted concentrations of radionuclides and soluble RCRA constituents in any brine present in WIPP disposal rooms, along with the volume and rate of brine release from the repository, constitute the source term for performance assessment modeling. The speciation, solubilities, and sorptive properties of radionuclides will determine their concentrations in any brine present.

The speciation, solubilities, and sorptive properties of the important actinide elements in TRU waste are sensitive to Eh and pH, which will vary greatly with time and over short distances in WIPP disposal rooms (see Activity S.1.1.5). It is therefore necessary to quantify the chemical behavior of the actinide elements over a wide range of expected repository conditions, considering possible ligand-complexing effects of a broad range of organic constituents (both unregulated and of RCRA concern). Unfortunately, there are no thermodynamic data (stability constants for organic or inorganic actinide complexes, solubility products for actinide-bearing solids, or distribution coefficients for the sorption of actinides by bentonite or iron oxides) for solutions with ionic strengths as high as likely WIPP brines ($I = 6$ to 8 M).

Initially, stability constants, and perhaps solubility products, will be measured for important actinide elements in likely WIPP brines under conditions expected prior to reactions between these brines and nonradioactive constituents of the waste. (Microbial degradation of nonradioactive constituents of the waste, anoxic corrosion of metals, and reactions between brine and proposed backfill additives could change the Eh and pH of these brines significantly.) After laboratory studies of repository chemistry indicate the possible ranges of Eh and pH following reactions between these brines and nonradioactive constituents of the waste, stability constants, and perhaps solubility products, will also be measured for the important actinide elements under those conditions expected (1) to exist after interaction of waste, backfill, and brine; and (2) to have the highest potential for high effective actinide solubility.

An ongoing sensitivity study is examining the relative effects of solubility and sorption on the concentrations of radionuclides in any brine that resaturates WIPP disposal rooms. This study will identify actinide sorption data necessary for predicting the source term.

Finally, transport of actinide elements by colloidal or other suspended particles could be significant. Studies of colloid formation will begin after sensitivity studies identify the conditions under which this form of transport could be important.

The specific objectives of the laboratory studies of radionuclide chemistry are (1) to determine, as a baseline, effective actinide solubilities in expected brine prior to interaction with waste and backfill; (2) to determine effective solubilities (including colloids) under those past-reaction conditions expected to have highest solubilities; and (3) to investigate the role of organic compounds (including VOCs) in affecting actinide solubility.

A.2.4 SEQUENCE

The sequence of each category of laboratory studies appears separately below.

Laboratory Studies of Microbial Degradation of Nonradioactive Simulated Waste

1. Determine whether potentially significant microbial processes occur under expected repository conditions. (Started 7/89.)

2. Quantify, under realistic conditions, the effects on the repository gas and water budgets of those potentially significant processes that actually occur. (Begin mid-FY90.)

3. Determine whether microorganisms responsible for important processes are likely to survive for periods sufficient to affect the long-term performance of the WIPP disposal system. (To be scheduled.)

4. Quantify, under realistic conditions, the effects on the chemical behavior of important radionuclides in TRU waste of any potentially significant microbial processes that actually occur under expected repository conditions. (To be scheduled.)

Laboratory Studies of Radiolysis

1. Determine whether radiolysis increases the bioavailability of plastics and rubbers. (Started 10/89.)

2. Quantify the effect of waste compaction on the radiolytic gas production rate. (Begin mid-FY90.)

Laboratory Studies of Anoxic Corrosion

1. Measure anoxic-corrosion rates for relevant iron and steel alloys in likely WIPP brines at 30°C, if possible. (Begin early FY90.)

2. Determine whether anoxic corrosion of iron and steel alloys occurs in the presence of water vapor and, if so, measure its rate. (Begin early FY90.)

3. Quantify the effects of high CO_2 and H_2 pressures on anoxic corrosion of iron and steel alloys at 30°C. (Begin mid-FY90.)

4. Determine whether anoxic corrosion of iron and steel alloys occurs in the presence of water absorbed by bentonite and, if so, measure its rate. (Begin early FY91.)

5. Determine whether anoxic corrosion of other metals in the WIPP inventory occurs and, if so, measure rates for these metals. (Begin late FY91.)

Laboratory Studies of Proposed Backfill Additives

1. Determine whether proposed backfill additives effectively remove gas or prevent its production. (Started 8/89.)

2. Quantify the effects of proposed backfill additives on repository chemistry. (Begin early FY90.)

Laboratory Studies of Radionuclide Chemistry

1. Measure stability constants, and perhaps solubility products, for the important actinide elements in likely WIPP brines under conditions expected prior to reactions between these brines and nonradioactive constituents of the waste. (Started 10/89.)

2. Measure stability constants, and perhaps solubility products, for important actinide elements in likely WIPP brines under conditions expected following reactions between these brines and nonradioactive constituents of the waste. (To be scheduled.)

3. Collect any necessary sorption data for important actinide elements for predicting the source term. (Begin mid-FY90.)

4. Determine the conditions under which colloids form. (To be scheduled.)

A.3 WIPP BIN-SCALE CH-TRU WASTE TESTS

A.3.1 RATIONALE

Both the compositions of gases generated by radioactive waste and generation rates as a function of time may affect releases from the WIPP repository. Evaluation of gas effects on potential release scenarios requires data that define the chemical reactions leading to gas generation and the amounts and rates of gases generated. Several kinds of data on the potential in situ behavior of CH-TRU waste are needed, e.g., (1) net gas composition, generation rates, and depletion rates as a function of time and several other waste-condition parameters; (2) definition of dissolved or mobilized chemical and radiochemical species for the radionuclide and soluble RCRA source term; and (3) systems interactions and synergisms between wastes and backfill. The net impact of radiolytic, bacterial, and chemical degradation can be adequately analyzed and evaluated in bin-scale tests with TRU wastes over a range of experimental conditions. The degree of experimental control and multiple test conditions planned for the bin-scale tests allow simpler and more straightforward data interpretation than will be possible in alcove tests. Test data are necessary for both analytical calculations and performance assessment predictions and for confirmation of smaller scale laboratory data on simulated wastes. The full spectrum of required data can be obtained from bin-scale tests combined with alcove tests (Activity S.1.3.2) and supporting laboratory tests (Activities S.1.1.4 and S.1.1.5).

A.3.2 OBJECTIVES

1. Quantify with a high degree of control net gas quantities, compositions, and generation and depletion rates from actual TRU wastes, as a function of waste type, time, and interactions with brines and other natural and engineered barrier materials in the repository. Experimental conditions primarily will represent the longer-term, postoperational phase of the repository and the operational phase.

2. Provide a larger-scale evaluation and extension of the laboratory test results, using actual TRU wastes under expected conditions.

3. Evaluate the synergistic impacts of microbial action, varying degrees of brine saturation, waste compaction, degradation product contamination, etc., on the gas generation capacity and radiochemical environment of TRU waste.

4. Incorporate long-term impacts of room closure and waste compaction on gas generation by including supercompacted wastes.

5. Evaluate the effectiveness of minimizing overall gas generation by incorporating getter materials, waste form modifications, and engineered modifications into the CH-TRU waste test system.

6. Measure solution leachate radiochemistry and hazardous constituent chemistry of brine-saturated TRU waste interactions as a function of credible environmental variables.

7. Determine the amount of volatile organic compounds and hazardous gases released by TRU wastes under realistic repository conditions to quantify how hazardous waste will affect the performance of the WIPP. The behavior of these gases will <u>not</u> be affected by reactive carbon composite filters during these tests, because the filters will not be used.

8. Provide gas generation and depletion data and source term information to support WIPP performance assessment, predictive modeling, and related evaluations and evaluate the validity of pertinent assumptions used in modeling.

9. Help establish an acceptable level of confidence in the WIPP performance assessment calculations and eliminate most "what if" questions and concerns.

A.3.3 DESCRIPTION

The primary purpose of the WIPP bin-scale CH-TRU waste test program (Molecke, 1989a) is to provide data and technical support to the WIPP Performance Assessment program for predictive modeling studies and for the assessment of hazardous-component release and consequent impacts on the WIPP, in relation to EPA concerns and regulations (40 CFR 191, 40 CFR 268). Specific data to be obtained include net compositions and net kinetic rates for gas production and consumption resulting from various CH-TRU waste degradation mechanisms. Similar data on potentially hazardous VOCs released by the waste and waste-brine leachate or source term radiochemistry will also be provided. CH-TRU waste will be used in these tests.

Net gas quantities and generation rates are expected to be significantly affected by and will be measured as a function of

- several representative classifications and types of CH-TRU waste;

- time (periodically, over several years);

- impacts of several types and quantities of intruding brines;

- impacts of waste interactions with salt, container metals, and backfill materials;

- aerobic and anaerobic environmental conditions representing the operational phase and longer-term, postoperational phase of the repository, respectively; and,

- impacts of potential gas getters and engineered modifications, particularly on gas consumption.

The waste gas production will also include the net effects of synergisms between the various degradation modes. Test conditions are tailored so that the effects of individual environmental variables on gas production can be separated.

Periodically collected gas samples from each test bin will be analyzed using an on-site, gas chromatography/mass spectrometer (GC/MS) to determine major and minor gas concentrations (including VOCs) and changes in composition as a function of time. The GC/MS analyses of all gases released at concentrations above 1 ppm allow rates of generation and depletion to be calculated. Evaluating the changes in gas compositions helps to determine the relative importance and kinetics of individual degradation mechanisms over time and the subsequent impacts of degradation by-products on further gas production. The important major gases to be analyzed, based on earlier, WIPP-specific laboratory testing (Zerwekh, 1979; Kosiewicz et al., 1979; Kosiewicz, 1980, 1981; Caldwell et al., 1987; Molecke, 1979), include hydrogen, carbon dioxide, carbon monoxide, methane, oxygen, water vapor, nitrogen, and specific injected tracer gases. Minor gases to be quantified potentially include VOCs (e.g., carbon tetrachloride, methylene chloride, xylenes, freons, and other organic solvents used at DOE waste generating facilities), radon, ammonia, hydrogen sulfide, nitrogen oxides, hydrogen chloride, and possibly others, as detectable. The major gases are primarily those generated or consumed by various waste-degradation mechanisms occurring within the test bin, or simply those remaining from the initial air atmosphere. Other minor gases may be sorbed in or on the wastes and eventually can be volatilized or can be generated by multiple secondary chemical and microbial waste degradation mechanisms.

Data collection will begin as soon as each test bin is emplaced, prepared, and sealed. Data and analyses from ongoing tests will be incorporated into the WIPP performance assessment calculations as available. These tests are expected to start providing significant data within weeks or months after test emplacement. Bin-scale testing will continue for a minimum of about 5 years, or until the data acquired are sufficient to provide confidence in the reliability of the information being obtained. At specific periods within the testing program, data will be analyzed and evaluated for input to ongoing performance assessment studies. At appropriate test intervals, data will be fully evaluated and documented in topical reports.

The bin-scale TRU waste program involves testing in multiple, large, instrumented metal bins containing specially prepared TRU wastes and appropriate material additives. Each WIPP test bin will be specially prepared and filled with TRU wastes at various DOE waste generator sites and will be shipped to WIPP for in situ testing. Prior to transferring the waste from the drums to the experimental bins at the generator sites, samples of the headspace gas will be taken and analyzed for organic and inorganic hazardous waste constituents. In addition, samples of the inorganic processing sludges will be obtained and analyzed for total VOCs and EP toxic metals. These analyses will provide baseline information for the bin experiments on the type and extent of hazardous waste constituents present in the experimental waste prior to emplacement underground at WIPP.

Each bin functions nominally as an independent, isolated, and controlled test system. The scope and scale of the tests will be adequately large to obtain the quantities and types of data needed. All TRU waste emplaced in WIPP during this test program must be retrievable. At the conclusion of the testing, all waste in bins will be retrieved. The tests will be conducted so that personnel and radiological safety are maintained. All test bins are planned to be isolated at WIPP within one underground test room, Room 1 of Panel 1; however, half of Room 2 of Panel 1 may be needed for later portions of the test program Room 2 of Panel 1 must be reserved for this purpose now.

The specially prepared wastes include up to about six, 55-gallon drum-volume equivalents of a specific type of CH-TRU wastes per bin. Four representative waste types have been selected for testing:

1. High-organic/newly generated wastes (HONG), both noncompacted and supercompacted (from the Rocky Flats Plant);

2. Low-organic/newly generated wastes (LONG), both noncompacted and supercompacted (from the Rocky Flats Plant);

3. High-organic/old wastes (HOOW); and

4. Inorganic processing sludges (PS).

The advantage of testing the in situ degradation behavior of supercompacted wastes is that such wastes are expected to be very similar to regular, noncompacted wastes that have been crushed and compacted in situ by long-term salt-creep closure of repository rooms, except for the relationship between long-term compaction and corrosion. Although these tests will simulate the geometric effects of compaction, they will not necessarily simulate the relation between corrosion and compaction. Impacts on gas generation caused by compaction (either at the generator site or by rapid in situ closure relative to corrosion) can thus be realistically evaluated during the course of these tests and factored into performance assessment calculations. Most high-organic ("soft") and low-organic ("hard," primarily metals and glasses) newly generated wastes at the Rocky Flats Plant will be supercompacted starting in 1990; these wastes will constitute a major fraction of TRU wastes to be shipped to the WIPP in the future. Other representative wastes (e.g., high-activity, organic sludges, specially processed) developed by the waste generators, waste types not currently shippable, waste types requiring further hazardous waste (RCRA) characterization, etc., may be defined and tested in Phase 3 of this test program. These waste types will be incorporated as available.

Four moistness conditions will be examined: (1) Dry, "as-received" (the expected case in the short term), (2) Moistened with Salado brine, about 1 percent by volume (the expected case within several years after decommissioning), (3) "Saturated" with Salado brine (a probable case in the long term); experimental restraints limit "saturation" to be about 10 percent added brine by volume (which should suffice to provide free brine), (4) Saturated with Castile brine (a possible occurrence in the long term, assuming human intrusion into a sealed repository). All brines will be injected into the test bins at the WIPP. All excess brines will be removed from the bins after test termination.

Various backfill and gas getter materials have been selected for testing to evaluate their impacts on gas production and consumption and for impacts on waste-brine-leachate solution radiochemistry and possibly hazardous component chemistry. Backfill combinations and emplacement geometry are to be representative of the postoperational phase, when CH-TRU waste containers are no longer expected to be intact, and the wastes and container materials will be directly layered or mixed with the salt and backfill materials. Selected backfill and getter materials are: none; WIPP rock salt; rock salt and bentonite clay (70 percent/30 percent); salt/bentonite and gas and/or radionuclide getter additives, to be specified later; and salt/others, i.e., grouts, also to be defined later. The definition of getter materials and other backfill materials depends on ongoing laboratory testing and development (Brush, 1989). When available, these materials will be added to the bin-scale test matrix.

Internal atmospheres of the test bins are initially controlled and will be representative of TRU wastes in both the short-term, post-emplacement period (aerobic) and later time periods (assumed anaerobic). Initial bin atmospheres can be modified by a combination of argon gas flushing and the use of an oxygen gettering or reactant system. All test waste bins will be injected with inert, nonradioactive tracer gases. These tracer gases will facilitate analysis and interpretation of the data by allowing a gas mass/volume balance to be conducted; gas leakage or inflow can thus be compensated for.

The study of potential anaerobic corrosion of metals within the wastes, as affected by other simultaneous degradation mechanisms, is a significant objective of this test. The initial internal atmosphere within most test bins will be made anaerobic; thereafter, production of gases from various degradation mechanisms will control whether each bin stays anaerobic.

CH-TRU HONG wastes will generate their own anaerobic H_2 and CO_2 atmosphere, primarily by means of radiolysis. However, there is some uncertainty that the bin internal atmosphere will become anaerobic during the available time interval of this program. Therefore, most HONG waste bins will be purged and made anaerobic at the start of the test. CH-TRU HOOW and LONG wastes will also be purged initially with argon gas until anaerobic. During repackaging of HOOW wastes into test bins, the (assumed) previously established anaerobic environment is replaced by air. Purging these test bins establishes an anaerobic atmosphere similar to the original environment, as presumably generated by both microbial and radiolytic degradation mechanisms. No initial gas flushing for the inorganic PS wastes will be conducted. Radiolytic depletion or production of oxygen from PS wastes will be quantified along with other released gases.

Most plastic bags encapsulating CH-TRU wastes within test bins will be "pre-breached," that is, punctured or sliced, during packaging. Pre-breaching procedures will be conducted at generator or preparer facilities. Pre-breaching permits both the release of gases and contact between and interactions of the wastes with injected brines, resident colonies of bacteria, internal humidity, and the other added material components within the bin. Pre-breaching is beneficial for both testing and transportation.

There will also be a limited number of test bins where no waste pre-breaching will be conducted. These test bins, with as-received wastes, will have no added brine nor other added components. They will be conducted with an initial, internal air (aerobic) environment. These bins are intended to provided gas-release data applicable solely to the short-term, operational phase of the WIPP repository, in comparison with most of the other test bins, initially made anaerobic, which provide gas production data specific to the postoperational phase. The as-received bins are directly parallel to similar WIPP alcove tests (Molecke, 1989b), also with as-received wastes, in test alcove TA2.

These leak-tight bins will have a closely controlled and sealed test environment, similar to an isolated, waste filled repository room. Each bin is equipped with redundant gas sampling and injection ports and redundant brine injection and sampling ports. Each bin is also equipped with integral, non-gas-sorbing particulate filters, so as to not affect the quantification of VOCs. Thus, any gases sampled or released will not contain particulate radioactive contaminants. However, the behavior of any VOCs present will not be affected by the carbon composite filters that will be used on drums emplaced normally into the WIPP. Associated test bin instrumentation includes remote reading thermocouples, pressure gages, pressure relief valves, gas flow/volume monitors, and oxygen-specific detectors. Each test bin and associated instruments will be closely controlled and monitored by a computerized data acquisition system.

The test bins are specifically designed to fit within a TRU SWB for transport to the WIPP and eventual post-test disposal. The SWBs, with test bins inside them, are transported within a TRUPACT-II shipping cask. The test bin is not a transportation or terminal disposal container; it is to be used for testing purposes only.

The bin-scale test program is planned to take place in three phases. (The three phases of the bin-scale test program are completely separate from the two phases of the alcove tests discussed in Section A.4.3.) Phase 1 can be initiated at WIPP in FY90 and will incorporate test bins where all components can now be defined. Backfill materials will be none, salt, or salt/bentonite. Approximately 48 waste-filled bins of different waste compositions and backfills, including replicates, will be included in Phase 1. Eight other, empty, Phase 1 test bins will be used for a pressure and gas-baseline reference during the test program. These 8 empty bins will be emplaced and hooked up in the WIPP in an early time frame, prior to first waste receipt. They will also be used to initiate, check out, and debug the test program, i.e., instruments, gas sampling, routine operations, etc., before waste-containing bins are emplaced.

Phase 2 tests will incorporate another 68 waste-containing bins, with more moisture conditions, gas-getter materials, and supercompacted high-organic and low-organic wastes. Initiation of much of Phase 2 would depend on supporting laboratory data (Brush, 1989), particularly as to the composition of gas getters or other backfill material components, and the availability of supercompacted wastes. Phase 2 tests are not expected to start before October 1990.

Phases 1 and 2 of the WIPP bin-scale CH-TRU test program incorporate a total of 124 test bins, 116 of which contain a total of about 608 drum-volume equivalents of CH-TRU wastes. Of these 124 test bins, 28 are basically dedicated to acquiring gas production data applicable to the short-term, operational phase of the WIPP repository; 88 are applicable to the longer-term, postoperational phase; and 8 are empty.

Phase 3 of the test program cannot be described in any detail at this time. Phase 3 test bins are required to accommodate potential test contingencies, specifically including any new engineering modifications to waste and backfill. These include alternative or processed waste forms, backfill materials, or getter materials that may be defined and developed in the future. If any additional engineered alternatives to reduce gas production are similarly defined in the future, they can also be tested for efficacy with actual TRU wastes in bin-scale tests. Future needs for additional test bins and drum-volumes of CH-TRU waste will be based on new developments, preliminary test results, perceived data needs, and possible WIPP Project decisions. Details of Phase 3 tests will be described in a future Test Plan addendum.

Detailed planning for the bin-scale tests will continue through late 1989, followed by procurement actions. Site preparation, including any necessary test preparation and installation, will also begin during 1989 and continue for about one year. First data acquisition for these tests is expected to start during FY90. Further descriptions and technical details of these bin-scale CH-TRU waste tests can be found in the Test Plan: WIPP Bin-Scale CH-TRU Waste Tests (Molecke, 1989a).

A.4 WIPP IN SITU ALCOVE CH-TRU WASTE TESTS

A.4.1 RATIONALE

Data on the net production, depletion, and composition of gases resulting from in situ degradation of representative mixes of CH-TRU wastes are needed to support performance assessment of long-term repository behavior (Activity S.1.2.4). Data on TRU waste-degradation rates must be representative of time periods extending from emplacement to the longer-term, postoperational phase. Data must be obtained in a controlled research mode, not simply as a monitoring function, to allow multiple degradation mechanisms and impacts to be assessed and to accelerate the experimental time frame relative to that expected in full-scale disposal.

Large-scale, underground alcove tests will help identify unexpected phenomena or problems, which can then be technically resolved to eliminate most "what if" questions or concerns prior to the end of the retrieval phase. There is no credible alternative to conducting alcove tests underground (in situ) at the WIPP in such a manner as to generate the confidence required of performance assessment. The full spectrum of gas data needed to address performance assessment concerns can be obtained when data from the alcove tests are combined with the parallel laboratory (Activities S.1.1.4 and S.1.1.5) and bin-scale (Activity S.1.3.3) tests. The alcove in situ data will be acquired from some of the first CH-TRU wastes to be emplaced in the WIPP.

A.4.2 OBJECTIVES

1. Determine baseline net gas quantities, compositions, and generation and depletion behavior rates for as-received, representative mixtures of TRU wastes in a typical, operational phase repository room environment (Phase 1).

2. Determine net gas quantities, compositions, and generation and depletion rates for a representative compositional range of specially prepared mixtures of actual TRU wastes (with and without compaction), backfill materials, gas getters, and intruding brine under generally representative, postoperational phase repository room conditions (Phase 2).

3. Determine the amount of VOCs released by TRU wastes under actual repository conditions, in order to quantify impacts of EPA hazardous waste regulations (40 CFR 268) on the WIPP.

4. Provide full-scale in situ test of gas getter effectiveness and waste room backfilling procedures (Phase 2).

5. Confirm, on an alcove scale, the validity of gas generation results and interpretations of the laboratory and bin-scale tests of TRU waste degradation and gas production.

6. Establish an acceptable level of confidence in performance assessment calculations that include gas generation and depletion with actual in situ gas measurements; help validate pertinent assumptions used in modeling.

A.4.3 DESCRIPTION

The primary purposes of the WIPP In Situ Alcove CH TRU Waste Test program are (1) to provide relevant data and technical support to the WIPP Performance Assessment for predictive modeling studies; and (2) to provide in situ data for assessing hazardous component releases and consequent impacts on the WIPP, in relation to EPA concerns and regulations. Specific data to be obtained include the net quantities, compositions, and kinetic rate data on gas production and consumption resulting from various CH-TRU waste degradation mechanisms. Similar data on potentially hazardous VOCs released by the waste will also be provided.

The alcove test program will sample and analyze gases released from mixtures of CH-TRU wastes that have been emplaced within isolated, atmosphere-controlled test alcoves underground at the WIPP. A test alcove is a room mined in the salt, with one blind end and one open end sealed with a leak-tight closure plug.

A test alcove is about one-quarter the volume and one-third the length of a standard WIPP waste storage room; each of the six planned WIPP test alcoves is approximately 100 feet long, 25 feet wide, and 13 feet high.

Various types of CH-TRU waste will be shipped to the WIPP for emplacement and in situ gas measurement testing. These wastes will include both "as-received," with no special processing, and "specially prepared" wastes. All TRU test wastes will be prepared and packaged at DOE waste-generator sites. TRU waste types to be used in this test program are essentially the same as those used for the bin-scale test program (Molecke, 1989a) These wastes are representative of the major portion of the TRU waste to be eventually isolated at WIPP and include HONG, LONG, PS, and HOOW wastes (Section A.3.3). The advantages of testing the in situ degradation behavior of supercompacted waste have also been discussed in Section A.3.3.

CH-TRU waste will be emplaced in five of the six WIPP test alcoves. Each alcove must contain a typical, representative quantity and mixture of waste types and waste loadings. About 1,050 drums or drum-volume equivalents (i.e., corresponding to the volume of a 210-liter/55-gallon drum) of standard, non-compacted waste, or about 350 drums of supercompacted waste, will be required per test alcove. Approximately 3,850 drum-volumes of TRU waste overall will be used in this test program. Waste quantities selected were based on both statistical evaluations and practical matters.

CH-TRU waste can release gases by multiple waste degradation mechanisms and associated processes. The major and minor gases to be analyzed in the alcove test program are identical to those to be analyzed in the bin-scale tests, described in Section A.3.3. Determining the amounts of VOC/hazardous gases released from actual TRU waste is an important objective of this test program.

Gas quantities, compositions, and generation rates can be significantly affected by and will be measured as a function of emplacement of several representative classifications and types and <u>mixtures</u> of CH-TRU wastes; time (periodically, over several years); variation in content of intruding, moistening brine; waste interactions with salt, container metals, and backfill materials; aerobic and anaerobic environmental conditions representing the operational phase and longer-term, postoperational phase of the repository, respectively; and emplacement of potential gas getters that surround or encapsulate the waste containers. The waste gas production results also include the synergy among the various waste materials and degradation modes.

Periodically collected gas samples from each test alcove will be analyzed using an on-site, gas chromatography/mass spectrometer (GC/MS) to determine major and minor gas compositions and concentrations, and changes thereof as a function of time. The GC/MS analyses of all gases released at a concentration above 1 ppm will allow calculation of their rates of generation and/or depletion. Evaluation of the changes in gas compositions will help determine the relative importance and kinetics of individual degradation mechanisms over time and of the impacts of degradation by-products on further gas production.

Gas data collection will begin as soon as each test alcove is filled with TRU waste, sealed, and the initial alcove gas atmosphere appropriately prepared. These tests are expected to start providing significant data within months after test emplacement. However, due to the slow rate of expected gas generation and the lack of sensitivity caused by the large, masking amount of gas atmosphere initially in the alcoves, it is expected that almost one year will be required before there is an adequate quantity and quality of data for interpretation. WIPP alcove testing will continue for a minimum of about five years, or until the data acquired are sufficient to provide confidence in the reliability of the information being obtained. Data will be analyzed and evaluated for input to ongoing WIPP performance assessment studies almost continuously. Data will be fully evaluated and documented in periodic topical reports.

Gas data from the WIPP in situ alcove CH-TRU waste will be acquired in two specific test phases. The first two test alcoves, together defined as Phase 1 of this program, will be used as a "proof of concept" that such gas measurements can be successfully conducted in the underground facility. The first sealed test alcove, TA1, will be empty (no waste) and will provide gas reference baseline data, i.e., compositions of trapped atmosphere, gases and moisture released from the rock salt, etc., for comparison with the waste-filled test alcoves. Alcove TA1 will also provide an initial pressure baseline for comparison with the other test alcoves.

Test alcove TA2 will contain a representative mixture of about 1,050 drums or drum-volume equivalents of as-received CH-TRU waste. These wastes will be packaged by waste generators into either standard 55-gallon drums or TRU SWBs. Both types of containers will be vented and particulate-filtered. Alcove TA2 will be used to provide data on CH-TRU waste gas generation under actual, in situ repository conditions (initial air atmosphere, dry/as-received, with no salt, backfill, or getter material in direct contact with the wastes) and is specifically representative of the short-term, operational phase of the repository. TA2 also provides the initial data for repository time t = 0, necessary for the Phase 2 tests.

Phase 2 of the alcove test program includes 4 alcoves and is specifically tailored to represent the long-term, postoperational phase of the WIPP repository. Phase 2 tailoring consists of three basic operations: alcove gas atmosphere control, waste special preparation, and brine injection of all wastes. It is assumed in the performance assessment that the repository will be anaerobic in the long-term, i.e., anoxic, less than 10 ppm O_2. Therefore, the atmosphere in each alcove will be initially prepared and kept anaerobic. This involves nitrogen gas flushing of each alcove and the continuous use of an oxygen-gettering reactant system. Thus, in contrast to the bin-scale tests, the anoxic condition of the alcove atmosphere will be a controlled rather than a free variable. The TRU wastes in each Phase 2 test container will be specially prepared and packaged as follows. There will be a specific type of TRU waste, either noncompacted or supercompacted, within each test drum or SWB. Any plastic bags encapsulating these wastes will be pre-breached. Pre-breaching permits contact and interaction of the wastes with other added components within the test container. This operation is beneficial for both testing and transportation (within TRUPACT-II casks). The wastes will be sandwiched between added layers of backfill materials (70 wt. percent WIPP crushed salt/30 wt. percent bentonite clay) and metal corrodant materials (mild steel wire mesh). One or two unbreached plastic bags will enclose all pre-breached wastes and other components within one total environment. These all-encompassing plastic bags, at the periphery of the waste container, are used to control contamination during waste packaging at the generator sites.

After emplacement in the WIPP, all Phase 2 TRU waste containers will be moistened with about 1 percent by volume of Salado brine; this is to represent the early stages of probable long-term brine intrusion before significant free brine is present. The brine will be a mixture of 90 percent by volume of artificially prepared brine and 10 percent of WIPP-collected Salado brine. Small amounts of brine, 2 liters/drum or 14 liters/SWB, will be injected through brine injection septa on the top of each container, through the unbreached plastic bags, into or onto the wastes inside.

Phase 2 test alcoves TA3 and TA5 will include specially prepared, noncompacted wastes, and TA4 and TA6 will include specially prepared, supercompacted wastes. Alcoves TA5 and TA6 will also include both backfill and gas getters, e.g., reactant, sorbent materials that encapsulate the wastes. Backfill and getter materials will be emplaced over and around the waste container stacks in these two test alcoves in a fully retrievable mode. All test wastes will be emplaced in such a manner to ensure that post-test retrieval is possible. Waste backfilling will be conducted for gas-mitigation tests and operational demonstrations. If other engineered alternatives to minimize TRU waste gas generation are available within the appropriate time, they could be added to alcoves TA5 and TA6 to test their in situ efficacy.

Initiation of Phase 2 testing in alcoves TA5 and TA6 depends on supporting laboratory data (Brush, 1989), particularly as to the composition and quantities of gas getters, other backfill material components, or proposed engineering modifications. These Phase 2 tests are not expected to start sooner than about FY92.

Detailed test planning for these in situ alcove CH-TRU waste tests will continue through FY89 and early FY90 and will be accompanied by procurement activities for test equipment, instruments, supplies, and the actual CH-TRU wastes. Site preparation, including any necessary mining and test installation, will also begin during FY89 and continue for about one year or more. Initial data acquisition from these tests, e.g., baseline-alcove gas analyses and interpretations, is expected to start during FY90. Gas analyses from the first waste filled alcove, TA2, is scheduled to start in FY91. These tests will continue for a minimum of about 5 years or until the data acquired are sufficient to provide confidence in the reliability of the information being obtained. Further descriptions and technical details of these WIPP In Situ Alcove CH TRU Waste Tests will be found in the Test Plan (Molecke, 1989b).

A.5 SEQUENCE FOR GAS GENERATION TESTING

The laboratory portion of the testing program has been initiated and will soon be followed by the bin-scale tests. These two tests will proceed concurrently with appropriate sequencing to permit early laboratory results to affect the configuration of the bin tests. For example, backfill additives to be evaluated for gas and brine sorption capability will be selected in laboratory tests and subsequently evaluated in bin-scale tests.

Additional laboratory tests will be initiated throughout the second quarter of FY89. The tests will provide data within one year, but some laboratory testing will continue for an additional year or until sufficient data and technical understanding of the phenomena are gained. At specific periods within the testing program, data will be analyzed and evaluated for input to ongoing performance assessment studies. At appropriate test intervals, data will be evaluated and documented in topical reports.

The analysis of all data obtained from laboratory, bin-scale, and alcove tests will be documented in periodic data evaluation and topical reports (approximately on a yearly basis) as appropriate for each phase of the experiments. These reports will contain reduced data and interpretations, evaluations, and conclusions about the results of the tests and the technical issues addressed. These reports will form part of the primary data base used in the performance assessment.

A.6 SUMMARY

The WIPP Project is committed to compliance with the EPA Standard, 40 CFR 191, Subpart B, and with regulations evolving from relevant portions of RCRA, 40 CFR 268. Performance of gas generation tests with actual TRU waste materials is required to accurately characterize the behavior of the repository under very complex conditions. The tests consist of laboratory studies using radioactive and nonradioactive simulated wastes, bin-scale tests with CH-TRU waste, and alcove tests with CH-TRU waste. These tests will provide the data and models to be used to evaluate the effects of gas generated by the waste in realistic environments for both the operational (short-term) and postoperational (long-term) periods. This information is necessary for application to the performance assessment to obtain results with a sufficient level of confidence to demonstrate compliance with the EPA Standard and other applicable regulations.

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Wolery, T.J., D.J. Isherwood, K.J. Jackson, J.M. Delany, and I. Puigdomenech, 1984. *EQ3/6: Status and Applications*, UCRL-91884; Lawrence Livermore National Laboratory, Livermore, CA.

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APPENDIX B

COMMENTS AND RESPONSES

NAS/NAE WIPP PANEL REVIEW COMMENTS ON DOE DOCUMENT DOE/WIPP 89-011
DRAFT PLAN FOR THE WASTE ISOLATION PILOT PLANT TEST PHASE:
PERFORMANCE ASSESSMENT AND OPERATIONS DEMONSTRATION

RESPONSES TO COMMENTS

1. *DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of long-term safety of the WIPP repository, as currently understood. The immediate purposes of such an assessment would be to:*

   (i) identify critical risks and issues
   (ii) articulate and document the rationale for currently proposed programs
   (iii) establish priorities for these programs with respect to their expected contributions to the safe-repository objective (see Appendix)
   (iv) stimulate early development of the iterative process of performance assessment priorities that is missing in the compliance-oriented "total system modeling" approach now being pursued.

   Response 1: The DOE agrees. The WIPP Project has performed numerous relatively short-term studies of the WIPP repository in the past. These studies have been used to guide the support and funding of experiments and studies within the WIPP Project. A historical sensitivity analysis review (Anderson et al., 1990) will be completed by mid-FY90 and will identify past studies that have used optimization and other techniques to focus the experimental programs for repository and component design (such as seals). The DOE has initiated sensitivity analyses using an integrated, systematic assessment that will be used to further assign priorities to the extent feasible (Marietta et al., 1990; Rechard et al., 1990).

   Both the FEIS and the draft SEIS were designed to evaluate the safety of the repository. The draft SEIS calculations, which used a deterministic approach, showed that factors inhibiting room closure and consolidation (principally gas generation) were the greatest threat to compliance in the event of human intrusion. Two demonstration documents (Marietta et al., 1989; Bertram-Howery et al., 1989) are scheduled to be completed by the end of 1989. This document will contain a preliminary probabilistic analysis of the cases examined in the draft SEIS. The demonstration will show how the PA methodology is applied to the undisturbed scenario and several human intrusion scenarios that are considered to be the most critical. For these scenarios, critical issues will be identified to the extent that the current state of knowledge, particularly of the disposal room, will allow. The calculations and analyses necessary for the demonstration will show how the "total system" models are used iteratively for examining priorities in the experimental programs. The draft SEIS and the demonstration documents are continuing a line of similar, short-term, overall assessments of the WIPP's long-term performance: Claiborne and Gera (1974) developed and analyzed several release events; five of Bingham and Barr's (1979) scenarios were analyzed in the FEIS. Hunter (1989) also examined a large number of processes that were found to be of no further interest.

   Earlier investigations focused on questions that were somewhat generic, and they examined specific processes, parameter values, and repository-design considerations that have now been resolved. Before 1985, no regulatory standard was in place, so the approach taken to showing the adequacy of the site and design was safety-oriented. For example, the FEIS calculated doses to persons arising from transport of radionuclides to the Pecos River (DOE, 1980, p. 9-139) over periods of over 10^6 years.

The promulgation of the EPA Standard shifted the emphasis of the assessments from doses to releases and from the Pecos River to the controlled area. Initial sensitivity analyses in direct support of the performance assessment revealed that brine-influx rates, radionuclide solubility, radionuclide inventory, and initial void volume were critical issues to be resolved before compliance with the standard could be demonstrated. At about the same time, in-situ experiments revealed that the permeability of the Salado Formation is a few orders of magnitude less than had been thought based on above-ground experiments. Analyses of the new data showed that gas generation rates and volumes are also critical issues (e.g., Lappin et al., 1989).

The DOE plans to brief the NAS/NAE WIPP Panel, EPA, EEG, and State of New Mexico on the results of these iterative performance assessment analyses every six months and provide a written summary annually.

Anderson, D. R., et al., 1990, in preparation, Review of Parameter Sensitivity Studies for the WIPP Project Through September, 1989, SAND89-2028, Sandia National Laboratories, Albuquerque, NM.

Bertram-Howery, S. G., et al., 1989, in preparation, Forecast of the Final Report for the Comparison with EPA 40 CFR 191, Subpart B, for the WIPP, SAND88-1452, Sandia National Laboratories, Albuquerque, NM.

Bingham, F. W., and G. E. Barr, 1979, Scenarios for Long-Term Release of Radionuclides From a Nuclear-Waste Repository in the Los Medanos Region of New Mexico, SAND78-1730, Sandia Laboratories, Albuquerque, NM.

Claiborne, H. C., and F. Gera, 1974, Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico, ORNL-TM-4639, Oak Ridge National Laboratory, Oak Ridge, TN.

Hunter, R. L., 1989, in preparation, Events and Processes for Constructing Scenarios for the Release of Transuranic Waste from the Waste Isolation Pilot Plant, Southeastern New Mexico, SAND89-2546, Sandia National Laboratories, Albuquerque, NM.

Lappin, A. R., R. L. Hunter, Eds., D. P. Garber, P. B. Davies, Associate Eds., 1989, Systems Analysis, Long-Term Radionuclide Transport and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1988, SAND89-0462, Sandia National Laboratories, Albuquerque, NM.

Marietta, M. G., et al., 1989, in preparation, Performance Assessment Methodology Demonstration: Methodology Development for Purposes of Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the WIPP, SAND89-2027, Sandia National Laboratories, Albuquerque, NM.

Marietta, M. G., et al., 1990, in preparation, Parameter and Boundary Condition Sensitivity Studies Related to Climate Variability and Scenario Screening for the WIPP Site, SAND89-2029, Sandia National Laboratories, Albuquerque, NM.

Rechard, R. P., et al., 1990, in preparation, Parameter Sensitivity Studies of Selected Components of the WIPP Repository System, SAND89-2030, Sandia National Laboratories, Albuquerque, NM.

2. *Urgent attention should be given to (i) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (ii) examining options for modifications to the waste as part of the resolution of the gas generation issue.*

Response 2: The DOE concurs with these recommendations.

(i) The DOE recognizes the need to ensure that coupled calculations are performed to examine the combined effects of the phenomena, including potential fracture development as a result of pressure. Activity S.3.2.5, Three-Dimensional Mechanistic Hydrological Transport Model of Facility, will consist in part of two-phase fluid-flow modeling that incorporates the impact of waste-generated gas, and will be coordinated with the coupled room closure and fluid-flow simulations of Activity S.1.2.4, Disposal Room Performance Model. Activity S.3.2.4, Brine Inflow Model, will assess the potential impact of waste-generated gas on brine inflow. If the experimental assessment of gas generation rates (laboratory, bin, and alcove tests) and preliminary two-phase simulations suggest that gas pressures will be high enough to generate or propagate fractures, then gas-induced fracture modeling will be carried out in conjunction with Activities S.3.2.2, Numerical Code Development, and S.3.2.6, Integrated Mechanical Model, Disturbed Rock Zone, and Excavation Effects. In addition, the sensitivity analyses conducted in response to Comment 1 will focus this effort.

(ii) The DOE has organized an Engineered Alternatives Task Force to evaluate the feasibility and effectiveness of alternatives to the present waste forms and facility design as well as passive surface markers (Activity S.1.2.5). Types of enhancements under consideration include processing of the wastes, modifying the storage room or panel configuration, and modifying the repository design to reduce the probability of human intrusion. Alternatives are currently being evaluated for feasibility with respect to availability of technology, cost, schedule, siting, worker exposure, transportation, and regulatory concerns.

The effectiveness of these alternatives is being evaluated in parallel with the feasibility studies by using a deterministic design analysis model to ascertain whether the enhancements significantly improve the relative performance of the disposal system with regard to migration of radionuclides and hazardous constituents. Alternative designs that pass the feasibility and effectiveness screening process will then be modeled using the formal

Performance Assessment methodology (Activities PA.8, PA.9) and more detailed mechanistic models to quantify the improvements gained by the proposed enhancements. Promising modifications to the backfill and/or waste forms will be tested as appropriate in bin and possibly alcove experiments (Activities S.1.1.4, S.1.3.2, S.1.3.3).

The DOE will brief the NAS/NAE WIPP Panel, EPA, EEG, and the State of New Mexico periodically on the progress of this study.

3. *Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5 percent by volume of the capacity of WIPP, are warranted and should begin without delay.*

Response 3: The DOE concurs with this recommendation. Although sites other than the WIPP are being considered for the experiments, current projections of availability show that it would be possible to carry out experiments at the WIPP sooner than elsewhere (Molecke, 1989). The DOE will be prepared to initiate experiments as soon as the institutional and technical requirements as identified in the Secretary's Decision Plan (Rev. 0, dated 10/11/89) are resolved and shipment of waste to WIPP is allowed or another site has been located and prepared.

Molecke, M. A., 1989, in preparation, Test Plan: WIPP Bin-Scale CH TRU Waste Tests, Sandia National Laboratories, Albuquerque, NM.

4. *Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., U.K.) should be collected and studied, together with engineering modifications, as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.*

Response 4: The DOE agrees with this comment. The DOE is planning a comprehensive series of laboratory tests to examine gas generation by bacteria, radiolysis, and corrosion, including appropriate tests at high pressures as recommended (Activity S.1.1.4). In addition, the DOE will incorporate gas generation information from waste generators, from the international community, and from recommendations of the Engineered Alternatives Task Force (see response to Comment 2) in its effort to resolve the gas generation issue. On November 6, 1989, SNL management and staff met with representatives of the U.K. low-level and TRU waste programs regarding their experience with gas generation. In addition, they are planning another trip to review U.K. and other gas-generation studies in detail.

5. *The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.*

Response 5: The DOE agrees, and a study comparing the transport of radioactive waste versus transport of other hazardous materials is underway. The report will be referenced in the revised Plan for the Test Phase. In addition, the Office of Technology Assessment of the U.S. Congress completed a comprehensive study of hazardous materials transport in 1986 (Office of Technology Assessment, 1986) that will also be cited.

The TRUPACT Safety Analysis Report provides detailed analyses of the consequences of various accident scenarios involving the transportation of TRU waste. The SEIS will also include an analysis of the risks associated with transportation.

Office of Technology Assessment, U.S. Congress, 1986, Hazardous Material Transport, OTA-SET-304, U.S. Government Printing Office, Washington, D.C.

6. *Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.*

Response 6: The detailed discussion of the Operations Demonstration Program has been deleted from the Plan. Following review of the Operations Demonstration by several external peer review groups (including the NAS/NAE WIPP Panel), the Secretary of Energy will make a decision as to the scope and timing of the Operations Demonstration. Based on the Secretary's decision, the DOE intends to develop a separate document describing the Operations Demonstration.

EPA REVIEW COMMENTS ON DOE DOCUMENT DOE/WIPP 89-011:
DRAFT PLAN FOR THE WASTE ISOLATION PILOT PLANT TEST PHASE
PERFORMANCE ASSESSMENT AND OPERATIONS DEMONSTRATION

RESPONSES TO COMMENTS

1. *DOE should, as recommended by the NAS, develop and publish within the next six months a systematic assessment of the long-term performance of the WIPP. EPA believes this assessment should include a simplified overview of the most important potential failure scenarios. This will help place the issues to be studied during the Test Phase into the context of the comprehensive performance assessment that will ultimately be needed.*

2. *DOE should use this systematic assessment as the first step towards developing the comprehensive performance assessment through several iterations. At each step, DOE should insure that the evolving assessment is reviewed by interested organizations such as the NAS, the New Mexico EEG and the EPA. Such systematic and continuing review by outside groups will help to insure the quality and completeness of the assessment.*

Response 1 and 2: The DOE agrees that it is valuable to perform relatively short-term studies periodically to ensure that the entire WIPP performance assessment and experimental program, which is a multi-year effort, is heading in the right direction. Both the FEIS (DOE, 1980) and the draft SEIS (DOE, 1989) were prepared to evaluate the environmental impacts and safety of the repository using conservative assumptions about important parameters. The draft SEIS examined two scenarios that are known to be of interest during the final performance assessment: undisturbed performance and human intrusion by drilling through the repository and into a Castile brine reservoir. By the end of 1989, two demonstration documents (Bertram-Howery et al., 1989; Marietta et al., 1989) will be published; they will also examine a limited number of scenarios that are known or thought to be particularly important. These documents will contain a preliminary probabilistic analysis of the cases examined in the draft SEIS. The demonstration will show how the PA methodology is applied to the undisturbed scenario and several human intrusion scenarios that are considered to be the most severe for compliance with the standard. The calculations and analyses necessary for the demonstration will show how the "total-system" models are used iteratively to examine priorities in experimental programs. The draft SEIS and the demonstration documents are continuing a line of similar, short-term, overall assessments of the WIPP's long-term performance: Claiborne and Gera (1974) developed and analyzed several release events; five of Bingham and Barr's (1979) scenarios were analyzed in the FEIS. Hunter (1989) also examined a large number of processes that were found to be of no further interest.

Earlier investigations focused on questions that were somewhat generic, and they examined specific processes, parameter values, and repository-design considerations that have now been resolved. Before 1985, no regulatory standard was in place, so the approach taken to showing the adequacy of the site and design was safety-oriented. For example, the FEIS calculated doses to persons arising from transport of radionuclides to the Pecos River (DOE, 1980, p. 9-139) over periods of over 10^6 years. In addition, a number of sensitivity analyses were used to determine the nature of the critical risks and issues (Anderson et al., 1990). The promulgation of the EPA Standard shifted the emphasis of the assessments from doses to releases and from the Pecos River to the controlled area. Initial sensitivity analyses in direct support of the performance assessment revealed that brine-influx rates, radionuclide solubility, radionuclide inventory, and initial void volume were critical issues to be resolved before compliance with the standard could be demonstrated. At about the same time, in-situ experiments revealed that the permeability of the Salado Formation is a few orders of magnitude less than had been thought based on above-ground experiments. Analyses of the new data showed that gas generation rates and volumes are also critical issues (e.g., Lappin et al., 1989). The DOE plans to brief the EPA, the NAS/NAE WIPP Panel, the State of New Mexico, and the EEG on the results of these analyses every six months and provide a written summary annually.

In the course of further analysis, the DOE may find that the performance of the disposal system is insensitive to some parameters that are now being investigated; unfortunately, it is difficult or impossible to determine in advance of the complete analysis which of the parameters these might be. Late in 1989 or early in 1990, the technical and scientific programs of the WIPP Project will be performing sensitivity analyses to determine the most important parameters in the overall performance assessment model (e.g., Marietta et al., 1990; Rechard et al., 1990) and will use these analyses as a guide in establishing program priorities.

Anderson, D. R., et al., 1990, Review of Parameter Sensitivity Studies for the WIPP Project Through September, 1989, SAND89-2028, Sandia National Laboratories, Albuquerque, NM.

Bertram-Howery, S. G., et al., 1989, in preparation, Forecast of the Final Report for the Comparison with EPA 40 CFR 191, Subpart B, for the WIPP, SAND88-1452, Sandia National Laboratories, Albuquerque, NM.

Bingham, F. W., and G. E. Barr, 1979, Scenarios for Long-Term Release of Radionuclides From a Nuclear-Waste Repository in the Los Medanos Region of New Mexico, SAND78-1730, Sandia Laboratories, Albuquerque, NM.

Claiborne, H. C., and F. Gera, 1974, Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico, ORNL-TM-4639, Oak Ridge National Laboratory, Oak Ridge, TN.

Hunter, R. L., 1989, in preparation, Events and Processes for Constructing Scenarios for the Release of Transuranic Waste from the Waste Isolation Pilot Plant, Southeastern New Mexico, SAND89-2546, Sandia National Laboratories, Albuquerque, NM.

Lappin, A. R., R. L. Hunter, Eds., D. P. Garber, P. B. Davies, Associate Eds., 1989, Systems Analysis, Long-Term Radionuclide Transport and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1988, SAND89-0462, Sandia National Laboratories, Albuquerque, NM.

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Rechard, R. P., et al., 1990, in preparation, Parameter Sensitivity Studies of Selected Components of the WIPP Repository System, SAND89-2030, Sandia National Laboratories, Albuquerque, NM.

U.S. Department of Energy, 1980, Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1989, Draft Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026-DS, U.S. Department of Energy, Washington, D.C.

3. *In concert with the six-month assessment of WIPP performance, DOE also should prepare an analytical comparison of the projected benefits, feasibility, costs, and short-term environmental effects of various waste treatment technologies and/or engineering improvements. This comparison should serve as the basis for selecting treatment technologies to include in expanded bin and alcove tests (see Recommendation 8). Also, the comparisons should be reviewed by the NAS, EEG and EPA. Further, it may help the Department in designing the baseline for the full-scale, instrumented pilot waste disposal rooms (see Recommendation 7).*

Response 3: The DOE has organized an Engineered Alternatives Task Force to evaluate the feasibility and effectiveness of alternatives to the present waste forms and facility design as well as passive surface markers (Activity S.1.2.5). Alternatives under consideration include processing of the wastes, modifying the storage room or panel configuration, and modifying the repository design to reduce the probability of human intrusion. Alternatives are currently being evaluated for feasibility with respect to availability of technology, cost, schedule, siting, worker exposure, transportation, and regulatory concerns.

The effectiveness of these alternatives is being evaluated in parallel with the feasibility studies by using a deterministic design analysis model to ascertain whether the enhancements significantly improve the relative performance of the disposal system. Alternative designs that pass the feasibility and effectiveness screening process will then be modeled using the formal Performance Assessment methodology (Activities PA.8, PA.9) and more detailed mechanistic models to quantify the improvements gained by the proposed modifications. In the case of modifications to the backfill or waste forms, it may be necessary to gather laboratory, bin, and/or alcove experimental data on the performance of these materials (Activities S.1.1.4, S.1.3.2, S.1.3.3).

The DOE will brief the EPA, NAS/NAE WIPP Panel, EEG, and the State of New Mexico periodically on the progress of this study.

4. *Throughout the Test Phase, DOE should publish the expected results of tests before the tests are actually conducted. These projections should then be compared with the actual results when they are available. Over time, this procedure should demonstrate the growing familiarity of the analysts with the waste disposal system and should enhance the confidence to be placed in the ultimate performance assessment.*

   Response 4: The DOE agrees that significant phenomena, parameter ranges, or parameter values should be documented prior to the conduct of a test. The expected results usually are described in reports, test plans, or internal memos. The type of documentation depends on the significance and scale of the experiment. Even when anticipated results do not closely fit actual results, much can be learned by analyzing the reasons for discrepancies. During the Test Phase, the DOE will require appropriate documentation of expected results of major tests (e.g., bin and alcove tests, circular brine room, rock mechanics tests). This documentation will be available to the EPA and to other technical review groups.

5. *As soon as possible, the Department should load a number of drums in an alcove with simulated wastes, including simulated leaks from the drums. The alcove should then be backfilled in a way that should be typical of later experiments. The Department should then demonstrate that it can safely recover these simulated wastes, together with any simulated contamination. This demonstration should provide confidence that the Department can perform any recovery operations that might be necessary for the real waste to be used during performance assessment testing.*

   Response 5: DOE will demonstrate the ability to safely retrieve waste from a backfilled alcove. It is expected to be similar to the demonstration performed for CH-TRU waste and reported in DOE-WIPP-88-006 dated January 28, 1988. It will use simulated waste and will include simulation of retrieval of damaged drums and of contaminated drums. Contamination will be simulated by the use of fluorescent powder. This demonstration will be performed prior to emplacing any waste in alcoves TA-5 and TA-6 with backfill. Transport to the surface and preparation for shipment will have been demonstrated earlier and would not need to be repeated for the backfilled alcoves.

6. *Characterization of gas composition with respect to RCRA constituents should be included by DOE in test protocols for laboratory studies of repository chemistry and for bin-scale and alcove-scale gas generation experiments.*

   Response 6: The DOE concurs with this recommendation. As part of the gas generation tests to be conducted in bin-scale experiments during the Test Phase, headspace gases will be sampled at the generator facilities during preparation of the waste bins. The gases from the different bin-scale and alcove experiments will be analyzed for volatile organics and major gases. The gas generation data will provide additional information on volatile organic constituents present in the waste. Leachate sampling in the bin experiments will provide additional information on the behavior of metal constituents. This information will be used in the analysis of the long-term performance of the repository.

7. *DOE should evaluate the feasibility of augmenting its test plan by the addition of two full-scale, instrumented, backfilled, sealed pilot waste disposal rooms. These rooms should be equipped with comprehensive monitoring systems for a wide range of parameters indicative of waste system performance, including, at a minimum: brine quantity, composition, and spatial distribution; gas quantity and composition; temperature distribution; backfilled mechanical state, including porosity, permeability, and degree of compaction and reconsolidation; extent of deformation of the surrounding roof, walls, and floor of the waste disposal room; and the occurrence of major brittle deformation in the roof or surrounding rock. The investigation of the feasibility of such a program should include, at a minimum, the availability of technology for sealing such a room to an extent sufficient for maintaining reasonable isolation and monitoring consistent with the objectives of the instrumentation program; a prior demonstration of DOE's capability to remove fully emplaced wastes in a state comparable to that expected in such a pilot test room ten years after emplacement; other design features for dealing with potential contingencies by measures less than removal of wastes, such as high integrity venting and/or drainage systems that would permit the long-term removal of quantities of gas or brine that might otherwise be deleterious to repository performance; the availability of instrumentation systems for remote monitoring and with expected lifetimes adequate to enable the test rooms to be monitored throughout the life of the WIPP repository; and the filling of such waste rooms with waste types and backfill materials for which there is high likelihood that gas generation and other processes will not later require removal of such wastes.*

Response 7: DOE agrees with the concept of monitoring the performance of the facility during the life of the project. Long-term monitoring in backfilled, sealed disposal rooms is beyond current instrumentation technology. DOE will evaluate the feasibility of limited short-term monitoring in backfilled, sealed pilot waste rooms. The types of parameters that will be examined are brine, gas, temperature, reconsolidation, and pressure. Following consultation with the EPA, NAS/NAE WIPP Panel, EEG, and State of New Mexico regarding the results of this study, the DOE will make a decision on the nature, scope, and timing of facility monitoring. The feasibility evaluation will also consider recoverability of the emplaced waste.

Data on the parameters suggested are being gathered by other tests and experiments in progress or planned for WIPP. For example:

1. Brine quantity, composition, and spatial distribution data have been gathered as part of the Brine Sampling and Evaluation Program (Activity S.3.3.13) and will be gathered by the Circular Room Brine Test (Activity S.3.3.8).

2. Gas quantity and composition data will be gathered in the gas baseline alcove (Activity S.1.3.2).

3. Data on backfilled mechanical state including porosity, permeability, and degree of compaction and reconsolidation will come from Room T experiments (Activity S.1.3.1) and from Test Alcoves 5 and 6 (Activity S.1.3.2).

4. Data on deformation of the surrounding roof, walls, and floors of the waste storage room and the occurrence of major brittle deformation in the roof or surrounding rock comes from the extensive geomechanical monitoring program that has been in progress for many years at WIPP, which includes the SPDV Test Rooms, the empty Panel 1 rooms, and the instrumenting and monitoring of numerous other areas.

8. *DOE should expand its entire repertoire of tests to include samples of waste that have been incinerated, immobilized, or treated by other technologies that DOE identifies as having the potential to significantly reduce problems with gas generation or to otherwise reduce the capability of radionuclides or hazardous constituents to migrate after disposal.*

Response 8: Some potential modifications to waste and backfill, including compacted/supercompacted waste and the addition of gas inhibitors/getters to current design-basis backfill, are already incorporated into the laboratory, bin, and alcove tests (Activities S.1.1.4, S.1.3.2, S.1.3.3.). Samples of additional modified waste forms and/or backfills will be incorporated into these tests as appropriate after the Engineered Alternatives Task Force has evaluated the feasibility and effectiveness of the modifications with respect to the migration of radionuclides and hazardous constituents (Activity S.1.2.5) (see response to Recommendation 3).

9. *Since the physical and chemical state of the backfilled rooms is an important consideration in the selection of parameters for most performance assessment models, it is important that the current investigations of getter material also provide information for use in performance assessments on how such model parameters might change from reference values that have been presented in the past when the assumption has been that the backfilled material would consist simply of crushed salt.*

Response 9: The DOE concurs with this recommendation, and several activities are in place to examine the chemical and physical state of backfilled rooms. Test Plan Activity S.1.1.1, Backfill-Mix Creep and Permeability Behavior, will examine the creep rates, permeability, and swelling of backfill mixtures containing bentonite or other additives. Activity S.1.1.2, Backfill-Mix Selection Tests, will investigate the possible use of tailored backfill in various configurations in the repository. Activity S.1.1.4, Laboratory Studies of Repository Chemistry, will quantify the chemical effects of proposed backfill additives that might function as gas getters. Activity S.1.2.1, Backfill-Mix Model, will develop a model to predict how nonsalt substances alter the rate of backfill consolidation, so that the effect on room closure and the final consolidated state of the room can be estimated. Activity S.1.2.3, Backfill-Mix Selection Analysis, will analyze candidate backfills in engineered configurations to determine how brine inflow, waste-container collapse, and other factors control the final state of room consolidation. Activity S.1.2.4, Disposal Room Performance Model, will develop a disposal-room model that incorporates backfill behavior. Activity S.1.2.5, Engineered Modifications, will examine various engineered alternatives to the backfills currently being considered. Activity S.1.3.3, Bin-Scale Gas Generation Tests, will also examine the effects of several alternative backfills on waste behavior. Thus, these activities will explicitly examine not only the effectiveness of getters but also the effects of getters on modeling parameters.

10. *Pumping and tracer tests to measure directional patterns in hydraulic conductivity should be augmented by geologic and/or geophysical studies of fracture patterns in individual boreholes, as well as area studies that correlate, insofar as possible, observed or inferred underground patterns of preferential fracturing with associated geologic processes such as underground dissolution and salt deformation.*

Response 10: Tracer tests at H-3, H-4, H-6, and H-11 and multipad hydraulic tests at H-3, WIPP-13, and H-11 have been performed and reported. Surface-based geophysical studies have been conducted to examine the Culebra for high transmissivity zones. Geophysical studies in individual boreholes to examine the spatial relationship of the high-transmissivity zone in the Culebra Dolomite to the waste-panel area are in progress (Activity S.4.3.8). Geologic studies of fractures in individual boreholes have been attempted, but the technique was not found to be be useful. The dolomites are vuggy, and the vugs do not follow regional stress fields. Because fractures are typically associated with vugs, very little can be learned by the study of individual fractures. The more apparent trend in transmissivity correlates with local dissolution in the Rustler Formation.

A report currently in preparation, <u>Conceptual Hydrogeologic Model of the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant Site, Southeastern New Mexico</u>, by Holt, Powers, Beauheim, and Crawley, SAND89-0862, will examine correlations between preferential fracturing and processes such as underground dissolution and salt deformation. This report is scheduled to be published early in 1990.

11. *DOE should conduct more comprehensive evaluations of past fluid movement in the Culebra unit by means of isotope studies and mineralogical or petrographic investigations of the Culebra Dolomite itself as well as vein-filling deposits. Furthermore, a conceptual model should be developed, consistent with the interpretation of such evidence from the past, for the coupling effects that would exist between a future pluvial climate and flow and geochemistry in the Culebra. Particular attention should be paid to the potential for increased future Culebra hydrologic conductivity as the result of dissolution of fracture filling deposits. While the focus of this recommendation is on the characteristics of the Culebra unit, it is anticipated that studies involving other associated units in the Rustler*

formation or in the Dewey Lake redbeds may contribute to an integrated understanding of past conditions.

Response 11: Some of the studies recommended by the EPA have been completed or are in progress. The potential for increased future Culebra hydrologic conductivity as the result of dissolution has been examined to the extent feasible and will be published as Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico, SAND88-0196, M. D. Siegel, S. J. Lambert, and K. L. Robinson, eds., in early 1990. Past fluid movement in the Culebra has been evaluated in the following papers:

Lambert, S. J., 1987, Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation, SAND86-1054, Sandia National Laboratories, Albuquerque, NM.

Lambert, S. J., and J. A. Carter, 1987, Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico, SAND87-0388, Sandia National Laboratories, Albuquerque, NM.

Lambert, S. J., and D. M. Harvey, 1987, Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico, SAND87-0318, Sandia National Laboratories, Albuquerque, NM.

In addition, a literature search of regional historical recharge/paleoclimate data will be performed. Sensitivity analysis studies will be performed on the ranges of data that resulted from the historical literature search.

12. *The DOE test plan should be augmented to include studies on the mechanism of fluid movement through the Salado formation both on the local scale (i.e., over distance of up to a few meters) and over a larger scale. Investigation of local scale movement should emphasize controlled laboratory investigation and bench scale testing. Larger scale analysis should include the validation of local models with available mineralogic or geochemical evidence on the history of past fluid movement or salt recrystallization in the Salado formation. Previous applications of Darcy's law as part of the interpretation of in situ experiments should be re-examined in the light of such research, and should also be examined for possible biasing effects of additional phenomena encountered under the actual test conditions, such as the brine off-gassing in the disturbed zone as a source of pressure or the deposition of dissolved salt near surfaces as a result of evaporation of brines.*

Response 12: DOE has several activities in progress to investigate the nature of (Darcy versus non-Darcy) fluid flow in the Salado Formation in situ. For example, Test Plan Activity S.3.3.4, Gas Flow/Permeability, will measure the relative permeability of the host rock to gas as a function of distance from the underground opening. Activity S.3.3.5, Near-Field Flow

Characterization, will examine the ability of the host rock to transmit fluids in the near field. Activity S.3.3.6, Brine Inflow Scale and Stratum Effects, will measure the effect of excavation scale on brine inflow. Activity S.3.3.7, Pore Pressure for Brine Inflow, will measure the near- and far-field distribution of pore pressures in order to infer the degree of interconnected flow. Activity S.3.3.8, Brine Inflow to Excavated Rooms, will test the scale-up capability of the brine-inflow model. Activity S.3.3.9, Brine Permeability Testing of the Disposal Horizon, will examine the far-field permeability of the Salado Formation. Activity S.3.3.10, Air Intake Shaft Brine Permeability Testing, will examine the ability of the Rustler and Salado Formations to provide fluid to the shafts. Activity S.3.3.11, Shaft Geophysics, will monitor the development of fractures and changes in porosity and permeability around a shaft. Activity S.3.3.12, Underground Geophysics, will measure changes in density, void volume, moisture, and permeability around backfilled rooms, facility host rock, and proposed seal locations. Activity S.3.3.13, Brine Sampling and Evaluation Program, will characterize the extent and composition of visually identified brine inflow. All these activities are investigating aspects of fluid movement through the Salado Formation.

Detailed studies of the Salado stratigraphy and depositional environments, including syn-sedimentary structures, solution, cementation, and diagenesis are presently being addressed as part of the geologic mapping of the Air Intake Shaft. This work is the necessary precursor to any future discussion of the age of any solutional and depositional features observed in the unit and of the history of past fluid movement through it. The report on the Air Intake Shaft will be available in early 1990. The results of these experiments will be used to develop the appropriate flow model. The implications of uncertainties in the Salado flow model were summarized by Lappin et al. (1989). Geochemical evaluations are also in progress.

Laboratory- and bench-scale tests of fluid flow in the salt are known to present difficulties that would require an advance in the state of the art: when samples are removed from the host rock, the stresses on the sample change, causing changes in the characteristics of the sample that may not be faithfully recovered under increased confining stress. Large-scale testing of the mechanism of flow is also impracticable, because measuring the extremely small flows through the formation (on the scale of meters) would require experiment times of years to decades.

Lappin, A. R., et al., eds., 1989, Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989, SAND89-0462, Sandia National Laboratories, Albuquerque, NM.

13. *The DOE test plan should investigate the mechanism and rates of fluid movement through interbeds at or close to the repository horizon.*

Response 13: The DOE concurs with this recommendation, and a number of activities are in progress to address the issue of fluid movement through interbeds. For example, Test Plan Activity S.3.3.7, Pore Pressure for

Brine Inflow, will measure the near- and far-field distribution of pore pressures in order to infer the degree of interconnected flow. Anhydrite beds (e.g., Marker Bed 139) and clay seams will be included among the test intervals. Activity S.3.3.9, Brine Permeability Testing of the Disposal Horizon, will examine the far-field permeability of the Salado Formation. Arrays of five drill holes will be used to conduct permeability tests at various intervals from 10 to 50 feet from the facility in the halites, polyhalites, anhydrites, and clay interbeds. These two activities will specifically examine various aspects of fluid movement in anhydrite and clay seams. In particular, ongoing testing in Room C-2 and in Room 7 of Panel 1 are examining mechanisms and rates of fluid movement in Marker Bed 139 in the far field and near field, respectively.

14. *DOE should investigate the potential long-term mobility of brine-filled fracture systems in marker bed 139 as a result of differential loading from the surrounding formation.*

Response 14: The DOE knows of no mechanism by which the fractures will move significantly in response to differential loading caused by regional variations in overburden thickness and density. DOE is investigating the way in which fractures form and enlarge and the way in which brine moves through fractures as a result of the differential loading created by the excavation of the underground openings themselves. This is the focus of many of the brine and excavation effects studies.

The specific phenomenon suggested in this comment should not occur, for two reasons. First, in order to propagate a fracture in the marker bed, the pressure in the fracture must be significantly above lithostatic pressure to overcome the strength of the rock; the pressure at the tip of the fracture cannot be above lithostatic, at that location, by definition. Second, in order for the proposed mechanism to work, even with sufficient pressure, a uniformly inclined plane from one end of the repository to the other must be present, which is not the case because the bedding in the Salado Formation undulates enough to disrupt any simple crack propagation. Even if the brine in the fracture were pressurized by gas, the range of the effect is limited, because the pressure in the repository produces a compressive stress field in the rock around the repository through which the crack cannot propagate.

15. *The DOE test plan should include an investigation of local and regional stress fields by means of in situ measurements and their correlation, insofar as possible, with observed geologic structures.*

Response 15: The local and regional stress fields have already been characterized adequately for the performance assessment. The Delaware Basin contains nearly flat-lying rocks over 200 million years in age. There is no indication of the existence of any regional stress field that could disrupt a waste disposal system. The few geologic structures that are present do not have tectonic origins. Therefore, the DOE does not think that the suggested regional studies would be of value. Local stress fields at the repository level have been investigated, and several reports have been published (e.g., Wawersik and Stone, 1985, 1989).

The Castile anhydrites and halites near the site were deformed because dense anhydrite overlies less dense halite. These same conditions already exist at the site, suggesting deformation may eventually occur there as well. New measurements of local or regional stresses are not expected to enhance our understanding of these conditions. Empirical strain rates, centrifuge studies, and computer models are consistent and indicate the evaporites at the site will not deform by this process until well after the period of regulatory concern. The rock units near the WIPP site were slightly tilted during late Permian to late Cenozoic time. The Ogallala Formation is untilted, indicating tilting is not later than late Miocene to early Pliocene.

The evaporite beds, especially the Castile Formation, near the WIPP site have been deformed in an area commonly referred to as the "disturbed zone" (Powers et al., 1978; Borns et al., 1983). The underlying Delaware Mountain Group has not been involved in the deformation, indicating that the process is driven by stresses and conditions within the evaporites. Borns et al. (1983) examined several alternative hypotheses and concluded that the rocks are being deformed by gravity as more dense anhydrite founders through less dense halite. These stresses exist throughout the eastern Delaware Basin, but the evaporites have not been uniformly deformed. Borns et al. (1983) hypothesize that an anomalous distribution of water within the Castile localized the deformation. Borns et al. (1983) used modeling studies and centrifuge studies, along with empirically derived strain rates for halite, to infer a period of 700,000 years to develop some of the observed structures and minimum times well in excess of 10,000 years for this structure to encroach on the WIPP location.

Borns, D. J., L. J. Barrows, D. W. Powers, and R. P. Snyder, 1983, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND82-1062, Sandia National Laboratories, Albuquerque, NM.

Powers, D. W., S. J. Lambert, S. E. Shaffer, L. R. Hill, and W. D. Weart, eds., 1978, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, SAND78-1596, Vol. I and II, Sandia National Laboratories, Albuquerque, NM.

Wawersik, W. R., and C. M. Stone, 1985, Application of Hydraulic Fracturing to Determine Virgin In Situ Stress State Around Waste Isolation Pilot Plant - In Situ Measurements, SAND85-1776, Sandia National Laboratories, Albuquerque, NM.

Wawersik, W. R., and C. M. Stone, 1989, "A Characterization of Pressure Records in Inelastic Rock Demonstrated by Hydraulic Fracturing Measurements in Salt," Special Issue, Hydraulic Fracturing Stress Measurements," Int. J. Rock Mech. Mi. Sci. (in press).

16. *The DOE test plan should include experiments designed to estimate the amount of waste that could be brought to the surface or otherwise impacted by future penetration of the repository by drilling.*

Response 16: The releases to the surface by drilling are controlled primarily by the shear strength of the waste/backfill mixture; low shear strengths allow greater releases than high shear strengths. WIPP calculations show that direct releases to the surface by drilling are small in comparison with the release limits in 40 CFR 191 unless the shear strength of the waste and backfill is extremely small. Sensitivity analyses are being performed to determine the range of shear strengths that would pose a threat to adequate containment. Experiments to estimate the shear strength of waste/backfill mixtures are planned (e.g., Activity S.1.1.3, Drum and Box Mechanical Response).

17. *The DOE test plan should include experiments to evaluate gas content of WIPP brines, and the effects of brine off-gassing on fluid transport. The results of this investigation should be applied both to the interpretation of brine inflow measurements from current experiments as well as an evaluation of future effects of this phenomenon on repository performance.*

    Response 17: The DOE concurs with this recommendation. Some gas composition data were collected from drillholes during field studies conducted in 1983 (Quarterly Geotechnical Field Data Report, WIPP-DOE-177). Sampling has begun to investigate brine off-gassing, and model modifications are required to examine two-phase-flow effects are being investigated. Possible effects include increased fluid flow in the event of human intrusion and the cessation of brine inflow and corrosion in response to elevated gas pressures.

18. *The DOE test plan should include experiments designed to measure the effects of gas pressure on the inflow of brine to disposal rooms. The scale of such experiments should be larger than individual boreholes in order to allow for the possible effects of gas pressure equilibration through microfractures and interbeds in the disturbed rock zone and the nearby zone of intact rock.*

    Response 18: Brine room Q, although not pressurized, will be of large scale and will integrate the effects of marker beds and the undisturbed rock zone into the observations. Some modeling is planned to address the issue of the effects of gas pressure on the inflow of brine to disposal rooms, but the experiments suggested are likely to be impracticable. The volume of brine flowing into underground rooms is small and spatially variable; determining the response of this flow to increased gas pressure would require extremely sensitive and sophisticated testing to ensure that pressure effects, and not some other type of effect, were being measured. Safety concerns associated with large volumes of pressurized gas in the underground preclude large-scale experiments of this nature. However, calculations investigating the mechanical response of the repository to elevated gas pressures are underway. In addition, present plans call for the excavation of a hydraulic fracturing test already conducted in Marker Bed 139 and the investigation of the relationship between internal gas loading rates and the pressure required for tensile fracturing.

19. *The DOE test plan and seal development program should consider the prediction of seal performance in the presence of large pressure differences over the seals.*

Response 19: A preliminary pressure-drop analysis for gas flow led to the conclusion that forces on seal components resulting from gas generation and flow are not expected to affect the performance of shaft seals (Lappin et al., 1989, p. 4-63 to 4-67). This preliminary analysis indicated that gas pressures no greater "than 5 to 5.5 MPa can exist at any time anywhere within the portion of the shaft between the lowest and middle composite shaft seals in the Salado formation... The lithostatic pressure exerted on the middle composite seal in the shaft...will be...at least 7 to 7.5 MPa. Therefore, the pressure of flowing gas is not expected to dislodge or damage the middle shaft seal."

Planned modeling studies include detailed analyses of the effects of potential gas generation in the waste-disposal area on the predicted performance of seal systems. Planned analyses include potential gas-generation effects on salt consolidation, on disturbed-zone behavior, and on overall seal-system performance throughout the required lifetime of the seals.

Lappin, A. R., R. L. Hunter, Eds., D. P. Garber, P. B. Davies, Associate Eds., 1989, Systems Analysis, Long-Term Radionuclide Transport and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1988, SAND89-0462, Sandia National Laboratories, Albuquerque, NM.

20. *The DOE test plan should include tests of the various seal materials for the purpose of demonstrating that seal integrity will not be compromised by the hazardous wastes disposed of at the WIPP during the design life of the seals.*

Response 20: The DOE concurs with this recommendation, and one activity has been modified to examine the potential effects of hazardous wastes on seal materials. Activity S.2.1.1, Geochemical Stability, will evaluate the potential for chemical degradation of seal materials as a result of interaction with hazardous components of the waste. The general discussion of sealing system activities, Section 2.6.2.2, also commits the sealing program to examine materials compatibility.

21. *DOE should validate its assumption that brittle failure due to salt movement is not a credible physical process in the Salado formation not only by qualitative arguments concerning the nature of salt and the application of rock mechanics models to the Salado formation as a whole, but also by reviewing the literature and the experience of the salt and potash industries to determine the extent of evidence for brittle failures associated with fault movement in similar evaporite basins. In particular, if DOE plans as part of its performance assessment to apply rock mechanics models to show expected plastic deformation in the presence of fault offsets in adjacent units, then it should apply these same models for validation purposes to one or more salt environments where brittle failure has been experimented in order to show that the models equally well predict the alternative behavior under the actual conditions present in these other locations.*

Response 21: It has not been demonstrated that the Salado Formation is faulted in the vicinity of the WIPP site; Hunter (1989) has calculated that the probability of faulting during the repository's lifetime is below the EPA's cutoff of 10^{-4} in 10^{4} years. Therefore, there are no plans in the WIPP performance assessment to model the effects of faulting, and no program to validate such models is necessary. However, the WIPP Project is in the process of modeling room closure and validating the models with tests. Room closure does entail brittle deformation in the near field, and experiments are being done to evaluate this time-dependent behavior.

Hunter, R. L., 1989, in preparation, Events and Processes for Constructing Scenarios for the Release of Transuranic Waste from the Waste Isolation Pilot Plant, Southeastern New Mexico, SAND89-2546, Sandia National Laboratories, Albuquerque, NM.

RESPONSES TO RECOMMENDATIONS OF THE
ENVIRONMENTAL EVALUATION GROUP'S
EVALUATION OF THE DOE PLANS FOR
RADIOACTIVE EXPERIMENTS AND OPERATIONAL DEMONSTRATION AT WIPP

RESPONSES TO COMMENTS

1. *DOE must publish the analyses that form the conclusions stated by DOE scientists at several presentations that WIPP has problems in showing compliance with the EPA Standards. In addition, a range of scenarios for breach should be analyzed and published, to isolate the factors that need to be better understood or for which mitigation measures must be developed.*

Response 1: The DOE agrees. By the end of 1989, a preliminary probabilistic analysis of the two cases examined in the SEIS and the five additional human-intrusion cases will be published. The demonstration will show how the PA methodology is applied to the undisturbed scenario and several human intrusion scenarios that are considered to be the most critical (Marietta et al., 1989). This document will contain complementary cumulative distribution functions (CCDFs) which show potential noncompliance when certain parameter values are assumed. Sensitivity analyses using an integrated, systematic assessment are in progress (Marietta et al., 1990). DOE will provide the EEG with copies of these documents by the end of 1989. A report to be published somewhat later will document the range of breaching scenarios that will be analyzed in the final performance assessment. The DOE will brief the NAS/NAE WIPP Panel, EPA, EEG, and State of New Mexico on the results of the iterative performance assessment analyses every six months and provide an annual written summary.

An unpublished draft memo written in 1987 was the first to show the potential difficulty of meeting the EPA standard if the WIPP is intruded. The EEG was briefed on the results of this work. The memo will be included as an appendix by Lappin et al. (1990).

Lappin, A. R., et al., 1990, in preparation, Systems Analysis, Long-Term Radionuclide Transport and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; September, 1989, SAND89-1996, Sandia National Laboratories, Albuquerque, NM.

Marietta, M. G., et al., 1989, in preparation, Performance Assessment Methodology Demonstration: Methodology Development for Purposes of Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the WIPP, SAND89-2027, Sandia National Laboratories, Albuquerque, NM.

Marietta, M. G., et al., 1990, in preparation, Parameter and Boundary Condition Sensitivity Studies Related to Climate Variability and Scenario Screening for the WIPP Site, SAND89-2029, Sandia National Laboratories, Albuquerque, NM.

2. *A realistic assessment of the effect of gas generation should be made. While the assumed "best estimate" of 2.55 moles/drum/year made by Lappin et al., (1989) is one-half of the "best estimate" using the same data (this report, p. 15), the predicted pressures (Lappin et al., 1989) in the repository (Table 2) are still too high. A more realistic assessment would consider the amount of brine that would be available; total time for bacterial action, radiolysis and corrosion; and the inter-relationship between different mechanisms of gas production. A better prediction of what may happen when the pressure in the repository begins to exceed the lithostatic pressure is also needed.*

Response 2: DOE agrees that iterative "realistic" assessments of gas-generation rates and potentials and of the effects of internal gas generation should be made. In general terms, the approach to numerical modeling of the response to internal gas pressurization is sequential. Initial calculations have assumed that the WIPP repository is emplaced in homogeneous, isotropic salt. Present calculations incorporate a slip line or fracture with zero tensile strength, with the objective of investigating far-field gas transport assuming zero matrix permeability. The final stage of calculations will incorporate variable far-field permeability within the Salado Formation, representative of the expected permeability of Marker Bed 139. It is presently anticipated that a revised gas-generation source term, combined with results of numerical modeling, should be formally available by August 1990. The NAS/NAE WIPP Panel, the EPA, the State of New Mexico, and the Environmental Evaluation Group will be briefed as these studies progress.

Until improved data become available from laboratory, bin-scale, and alcove tests, however, as well as from borehole studies of the response to elevated gas pressures, all current estimates of gas generation and its effects are uncertain. The laboratory, bin-scale, and alcove tests, all of which use real or simulated wastes at near ambient pressures, are specifically designed to obtain data to support assessment of gas-generation rates and potentials; both field and modeling studies will address the response of the WIPP to internal gas pressurization, without employing any real or simulated wastes. A definitive revision of the gas-generation rates and potentials awaits experimental data, especially under "humid" as opposed to brine-saturated conditions; preliminary results should be available in briefing format in December 1989.

The DOE is working to improve the estimate of gas generation behavior with both as-received and modified waste and backfill for three gas-generation time frames: (a) operational phase (including consideration of active venting), (b) near-term post-operational phase (the time between seal emplacement and salt compaction that gives rise to effective sealing), and (c) long-term post-operational phase (after effective sealing occurs). The present estimate of gas-generation rates assumes continuous brine saturation, which is obviously unrealistic for the operational phase, and which may be unrealistic, given the rates of brine inflow and backfill characteristics for the near-term post-operational phase as well. In fact, because of internal gas pressurization, it may even be unrealistic for long-term post-operational phase.

3. *Based on the information to date, it seems very likely that some engineered modifications will be needed to assure long-term integrity of the WIPP repository. Theoretical and experimental studies for possible modifications should begin immediately.*

Response 3: The DOE concurs with this recommendation and has organized an Engineered Alternatives Task Force to evaluate the feasibility and effectiveness of alternatives to the present waste forms and facility design as well as passive surface markers (Activity S.1.2.5). Types of alternatives under consideration include processing of the wastes, modifying the backfill by adding materials to counteract or prevent gas formation, modifying the storage room or panel configuration, and modifying the repository design to reduce the probability of human intrusion. Alternatives are currently being evaluated for feasibility with respect to availability of technology, cost, schedule, siting, worker exposure, transportation, and regulatory concerns.

The effectiveness of these alternatives is being evaluated in parallel with the feasibility studies by using a deterministic design analysis model to ascertain whether the enhancements significantly improve the relative performance of the disposal system. Alternative designs that pass the feasibility and effectiveness screening process will then be modeled using the formal Performance Assessment methodology (Activities PA.8 and PA.9) and more detailed mechanistic methods to quantify the improvements gained by the proposed modifications. In addition, promising modifications to the backfill and/or waste forms will be tested in laboratory, bin-scale, and/or alcove experiments to demonstrate their relative effectiveness (Activities S.1.1.4, S.1.3.3, and S.1.3.2). The DOE will brief the NAS/NAE WIPP Panel, EPA, EEG, and the State of New Mexico periodically on the progress of the study.

4. *Based on the assumption that additional data may help in making better predictions, planning should continue for designing the gas experiments. The bin-scale experiments should be expanded to include the study of engineered modifications, including various kinds of getters and modified waste forms (cemented, incinerated, etc.) and should begin without further delay. The plan for alcove tests needs more refinement to establish that there is a possibility of obtaining quantitative data in time for performance assessment and that experimental problems (e.g., room sealing) are manageable. In proceeding with these experiments, however, it should be kept in mind that the results will most likely not help in showing compliance with the EPA Standards.*

Response 4: The DOE will be prepared to initiate bin and alcove experiments as soon as the institutional and technical requirements, as identified in the Secretary's Decision Plan (Rev. 0, dated 10/11/89), are resolved and shipment of the waste to WIPP is allowed. Although sites other than the WIPP are being considered for the bin experiments, current projections of availability show that it would be possible to carry out experiments at the WIPP sooner than elsewhere (Molecke, 1989). The date for performance assessment (final consequence analysis) is a target date, rather than a mandatory milestone. If critical data are unavailable for the performance assessment to meet the target date, then the final performance assessment will be revised accordingly. Potential experimental problems such as alcove sealing are being addressed by proof-of-principle tests to be sure they are manageable.

The detailed design of the gas tests is in progress. Some modifications to waste and backfill, including compacted/supercompacted waste and addition of gas inhibitors/getters to present design-basis backfill are already incorporated into the laboratory, bin, and alcove tests. Samples of additional modified waste forms and/or backfills will be incorporated into laboratory, bin, and possibly alcove tests as appropriate after the Engineered Alternatives Task Force has evaluated the feasibility and effectiveness of the modifications (Activities S.1.1.4 and S.1.3.3).

Molecke, M. A., 1989, in preparation, Test Plan: WIPP Bin-Scale CH TRU Waste Tests, Sandia National Laboratories, Albuquerque, NM.