THE WIPP RESEARCH AND DEVELOPMENT PROGRAM: PROVIDING THE TECHNICAL BASIS FOR DEFENSE WASTE DISPOSAL

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, is being developed by the US Department of Energy as a research and development facility to demonstrate the safe disposal of radioactive wastes from the defense programs of the United States. Underground workings are at a depth of 660 m in a bedded-salt formation. Site investigations began in the early 1970s and are culminating with the completion of the Site and Preliminary Design Validation (SPDV) program in 1983 in which two shafts and several thousand feet of underground drifts are being constructed.

The underground facility will be used for in situ tests and demonstrations that address technical issues associated with the disposal of transuranic and defense high-level wastes (DHLW) in bedded salt. These tests are based on several years of laboratory tests, field tests in mines, and analytical modeling studies. They primarily address (1) repository development in bedded salt, including thermal-structural interactions, plugging and sealing, and facility operations; and (2) waste package interactions, including the effects of the waste on local rock salt and the evaluation of waste package materials.

In situ testing began in the WIPP with the initiation of the SPDV program in 1981. In 1983, a major series of tests will begin to investigate the response of the rock salt without the use of any radioactivity. These tests will include underground rooms simulating the configuration of a representative DHLW repository with an extraction ratio of about 25% and a heat loading of 12 W/m^2. Other tests will include overtests in which heat loadings are increased to bound the possible effects and to determine design margins. In the late 1980s, radioactive experiments will be performed with actual TRU and DHLW waste forms from the US defense programs. Then together, these experiments, the associated performance-assessment modeling, and the design and operation demonstrations will establish the technical basis for a defense waste repository in bedded salt.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a research and development (R&D) facility to demonstrate the safe disposal of wastes arising from the defense programs of the United States. It will provide an underground facility for in situ experiments and demonstrations that will resolve technical issues associated with the disposal of transuranic (TRU) and defense high-level wastes (DHLW) in bedded rock salt. Until 1981, the WIPP R&D program consisted of characterization and selection of the site in southeastern New Mexico and an experimental program incorporating the development of predictive models, laboratory experiments, and field tests in boreholes and nearby mines. In 1981, activities began on a series of in situ experiments to investigate the characteristics and response of the rock salt without the use of any radioactivity. In the late 1980s, a series of experiments are planned using actual waste from US defense programs. In this paper, technical issues for waste disposal in salt, the technical achievements to date relative to these issues, and the commensurate experiments planned for the WIPP are reviewed.

As site characterization and validation are completed, emphasis is being placed on performing those experiments and demonstrations that will establish the technical basis for a defense waste repository.[1] These experiments primarily address technical issues associated with repository and waste package development.

BACKGROUND

The in situ tests in the WIPP are based on an extensive background of predictive model development and laboratory and field testing. For repository development, these activities have addressed methods of designing and assessing the response of underground configurations to achieve stable rooms during operation and to predict the long-term response, including the ultimate closure and encapsulation of waste. Reference constitutive models have been developed from an extensive suite of laboratory tests on cores taken at depth at the WIPP site. These constitutive models characterize both the halite and nonhalite (e.g., anhydrite, polyhalite, and mixtures of various evaporites) rocks, and they incorporate elastic, thermal, and creep behavior. Such models are incorporated into two-dimensional finite-element computer codes to predict the temperature, stress, and deformation fields associated with excavation and waste emplacement. Numerical model development has included a benchmark comparison of available codes in the US and one from the Federal Republic of Germany.[2]

Plugging and sealing activities for the WIPP project have included the development of materials tailored to the lithology at the WIPP site. These materials include the cement-based grouts typically used in oil-field applications, and natural materials such as reconsolidated rocksalt or clays. A combination of these materials will be selectively emplaced to seal the shafts, drifts, and exploratory boreholes with prescribed boundaries around the underground workings.[3] Some of these materials have been tested in boreholes; in one test, a short (2 m) plug was subjected to 1800 psi pressure differentials, 1372 m below the surface. This plug effectively limited fluid flow with permeabilities on the order of 50 microdarcies.[4]

The experimental program for the WIPP has also addressed the potential interactions between defense radioactive wastes and rocksalts. These interactions include the effect of the heat and radiation on the rocksalt, the resulting environment imposed on the waste package, and the response of waste-package materials to that environment.

Brine-migration studies have included laboratory tests and a series of field tests in both domed and bedded salt. These experimental data were correlated with theoretical models, and projections were made of the maximum quantities of brine that might be expected. The projections were less than 20 liters per canister over a 1000-year period, indicating that brine migration is not a significant issue for repository development in salt.[5] These projections will be confirmed as part of the in situ experiments.

Materials for waste canisters/overpacks have been under extensive evaluation. Numerous metallic alloys have been evaluated. Some (e.g., titanium) have general corrosion rates on the order of a few micrometers per year in brine solutions at 250°C. Likewise, even steel, if thick enough (10 cm or so) could protect against general corrosion for periods exceeding 1000 years. Tests have been performed with a wide range of temperatures and oxidation conditions and have included the effects of gamma radiation.[6] These tests indicated that general corrosion is unlikely to be a limiting problem. Hence, current programs are addressing the impact of localized corrosion, stress-corrosion cracking, hydrogen embrittlement, and mechanistic studies to allow long-term predictions and accelerated testing.

Tailored backfill with mixtures of such materials as smectite clays (bentonite), sand, and granulated salt have been and are being evaluated. Many of these materials exhibit high sorption properties (particularly for transuranic elements) and geochemical stability, but at the same time increase the temperature of the canister and waste form and require additional excavation for emplacement.[7]

IN SITU TESTS

The first phase of in situ tests began with the Site and Preliminary Design Validation (SPDV) Program, which includes two shafts (3.66 and 1.83 m diameter) drilled to a depth of 656 m and a series of underground rooms. The SPDV will allow underground characterization of the rocks at the facility horizon and the overlying rocks by mapping of the shafts, drifts, and underground rooms. This information will be used to complete the data base obtained in an earlier site characterization program and more recent geophysical investigations and exploratory boreholes, thereby allowing a final assessment of the validity of the site for the mission of the WIPP.

The SPDV will also include geomechanical evaluations of the response of underground openings. Instrumentation is being emplaced in the shafts, drifts, and simulated storage rooms to monitor deformation of the rock under ambient conditions. Many rock samples will also be taken to examine the mineralogy and physical properties of the rocksalt and interbeds. The SPDV will be completed in 1983, although much of the data recording and analysis will continue for several years.

Following the SPDV, a series of technology experiments will be performed beginning in late 1983 that will address technical issues associated with the disposal of TRU and DHLW. The experiments will not use radioactive waste, but will include:[1]

- Thermal/Structural Interaction (TSI) Experiments
- Plugging and Sealing Experiments
- Operations Experiments
- Waste Package Performance Experiments

Thermal/Structural Interaction (TSI) Experiments

Rock mechanics plays a key role in understanding the behavior of a mined geologic repository because of the response of the host rock to excavation and heat from nuclear waste. In bedded salt, the principal issues are associated with (1) the development of stable rooms during the operational period for waste emplacement and retrieval, and (2) sufficient deformation of the rock to provide for long-term encapsulation, or sealing, of the waste. A series of tests are planned to address these issues.

<u>12-W/m^2 Mockup for DHLW</u>--This test will simulate the reference-repository conditions in a DHLW repository. It will be used to establish the temperatures, stresses, and displacements in the rock salt. It will also contribute to the validation of analytical procedure for making predictions of these effects. Electric heater arrays will be installed in three rooms each 5.5 m high x 5.5 m wide. The center room will have two rows of 310-W heaters simulating a thermal loading of 12 W/m^2.

<u>Overtest for Simulated DHLW</u>--This test will provide data on rock response under overtest (or bounding) conditions. These data will aid in validating predictive techniques, including materials for room backfill, at higher temperatures. It will also serve as a precursor for experiments with defense wastes at overtest temperatures. A single instrumented room (5.5 m high x 5.5 m wide) will contain electric heaters that produce a heat flux about 4 times that of the reference case. Maximum salt temperatures of 250°C will be approached.

<u>Geomechanical Evaluation</u>--This test will provide geomechanical data that will aid in validating

predictive techniques concerning the behavior of various-sized rooms and pillars, intersections of drifts, sequential mining, and the mode of pillar failure. Various drift, room, and pillar configurations are established to provide the required data.

Heated Axisymmetric Pillar--This test will determine the response of a large volume of salt at elevated temperatures by examining an axisymmetrical salt pillar under conditions of high stress and temperature. The 11-m-dia isolated salt pillar is surrounded by a surface blanket heater and a room 5.5 m high x 16.3 m wide.

In Situ Stress Field--This test is designed to assist in the determination of the initial state of stress in virgin host rock through the use of hydrofrac techniques. A borehole 100 mm in diameter and about 182 m long will be drilled horizontally along a future long drift alignment.

Plugging and Sealing Experiments

The development of techniques for adequately plugging and sealing penetrations in salt and associated rock types is needed to establish confidence in long-term isolation of radioactive waste. Models are available to evaluate the flow of fluids through drillholes and shafts. Candidate plugging materials, such as crushed salt or grout mixes of either fresh water or brine, are being evaluated in laboratory studies. The Bell Canyon Test program demonstrated the field plugging capability of cementitious grouts in anhydrite. However, material-emplacement techniques, plug design criteria, geochemical interactions, backfill reconsolidation, and performance assessment require further evaluation under in situ conditions. Tests to address plugging and sealing of penetrations (drifts) at the level of the underground workings will be performed. These are summarized below.

Permeability Measurements--This test will determine the in situ permeability of the facility salt formation and adjacent beds and obtain comparative values of permeability for the candidate plugging and sealing materials. Horizontal 200-mm-dia boreholes 2 m deep in the salt pillar will be pressurized for measuring gas and liquid permeabilities. Tests will be performed with cementitious grouts, clays, and salt backfills, including the effect of reconsolidation with time on permeability.

Size Effects--This test will determine the size and scaling relations for plugs and backfill materials and will develop emplacement techniques for room or drift backfills. Horizontal openings ranging from 200 mm in diameter to a quarter-size nominal drift configuration will be backfilled with candidate materials. Test sections associated with other experiments will also be used for emplacement evaluation.

Plug Test Matrix--This test will develop emplacement techniques for candidate materials and evaluate long-term interactions with the host rock by providing specimens for subsequent laboratory testing. Drillholes 100 mm in diameter and 1.5 m deep will be filled with candidate plug materials and allowed to cure in wet, dry, and heated conditions. Recovery and evaluation of the seal specimens will occur over the operating lifetime of the facility.

Operations Experiments

Radioactive material-handling operations at an experimental facility, including receipt and transfer of containers from the surface to underground rooms, have been demonstrated at a relatively small scale in Project Salt Vault, at the Asse Mine in the Federal Republic of Germany, and at the Nevada Test Site CLIMAX facility. Operational concepts for handling TRU and DHLW at the WIPP facility have been developed, and system designs are under way. Contact-handled (CH) TRU wastes are to be placed in drums and stacked by forklift in disposal-demonstration rooms. Remotely handled (RH) wastes are to be contained in cylindrical canisters and emplaced horizontally in the pillars of the TRU disposal-demonstration rooms. For the DHLW test rooms, canisters are to be emplaced vertically in the floor. Full-size demonstrations of emplacement and retrieval of material containers for simulated and radioactive waste are needed to develop a high level of confidence in handling procedures. Demonstrations are proposed both with and without radioactivity. Those without radioactivity are said to use "mock" waste. The planned tests to address the technical issues concerning waste handling operations are summarized below.

Mock DHLW Emplacement and Retrieval Demo--This test is designed to establish procedures for emplacing and retrieving DHLW canisters through the use of equipment for remotely handling DHLW waste. A reference DHLW room (5.5 m x 5.5 m) will be used to demonstrate emplacement and retrieval (by overcoring operations) of mock DHLW canisters in ambient and heated evironments. The data obtained will be used to document procedures and establish designs for equipment.

Mock TRU Waste Handling Demo--This test will demonstrate the capability of equipment, personnel, and procedures to emplace and retrieve CH and RH TRU waste. A TRU disposal demonstration room, 4 m high x 10 m wide, will be used to demonstrate the safe emplacement and retrieval of TRU drums and the horizontal emplacement and retrieval of RH canisters.

Waste Package Performance Experiment

The WIPP in situ tests will include experiments for validating and extending the long-term performance predictions for waste packages based on modeling and laboratory results. These experiments will establish the magnitude of the waste rock interactions and will demonstrate under actual environmental conditions the ability of waste packages to provide containment of radioactivity. The tests without radioactivity will include the following:

Simulated-Waste Package Performance--This test is designed to evaluate the adequacy, durability, and design options of simulated DHLW packages and engineered barrier materials under accelerated conditions. Waste packages will be placed in two different thermal environments (12 W/m^2 and overtest) in DHLW room configurations, and brine will be injected into the backfill during some of the tests.

Brine Migration--This test will establish the baseline volume of fluid produced at a waste package emplacement hole. Installation of radiant heaters in emplacement holes will permit an evaluation of fluid migration. These data will be compared with those from many fields at other sites obtained by using similar experimental apparatus.

TRU-Waste Drum Durability--This test will evaluate TRU drum corrosion in dry and wet conditions and evaluates the effects of backfill materials on durability. TRU-waste drums (210 L) will be subjected to different environmental conditions in an actual storage room configuration.

The underground configuration showing the excavation of the rooms for these experiments and the SPDV experiments is shown in Fig. 1. The excavation to date has included the two shafts, an exploratory drift 1000 m to the south, and a portion of the drifts and room to the north of the shafts. Data and measurements are obtained from the SPDV experiments as the excavation continues.

The technology experiments are now in the final design stages. Detailed test plans are being prepared. The specifications for the underground configuration are being used to prepare construction drawings. Geomechanical instrumentation is being evaluated and procured. A data-acquisition system capable of recording and processing 2000 channels has been incorporated into an instrumentation trailer that will be located at the surface near the shaft. Excavation will begin in late 1983, immediately followed by instrumentation to monitor the ambient response. In early 1984, heaters will be emplaced and the thermal effects will be observed. Plugging and sealing experiments and operations demonstrations can also begin at that time.

Tests With Radioactivity

Following these tests and the completion of the radioactive handling facility at the WIPP, experiments and demonstrations can begin with radioactive wastes. These will include a full-scale demonstration of TRU disposal operations and tests with up to 40 canisters of DHLW. The TRU waste emplacement will initially be a pilot operation that, if successfully completed,[1] can be expanded to a full operation with 179,000 m^3 of waste and about 100 acres of underground facility area. The DHLW tests will include wastes under reference cases and overtest conditions in which temperatures, radiation levels, and brine concentrations will be enhanced to accelerate effects and to determine design margins. Waste used in these tests will be retrieved upon completion of the experiments.

SUMMARY

The WIPP is an R&D facility that includes a phased program of site characterization, in situ tests, and operations demonstrations. It addresses all the technical issues associated with TRU and DHLW from US defense programs. Underground construction is in progress, and data collection from experiments without radioactivity will begin in 1983. Radioactive experiments can be performed in the late 1980s, thus providing a comprehensive technical basis for the disposal of defense wastes in bedded salt.

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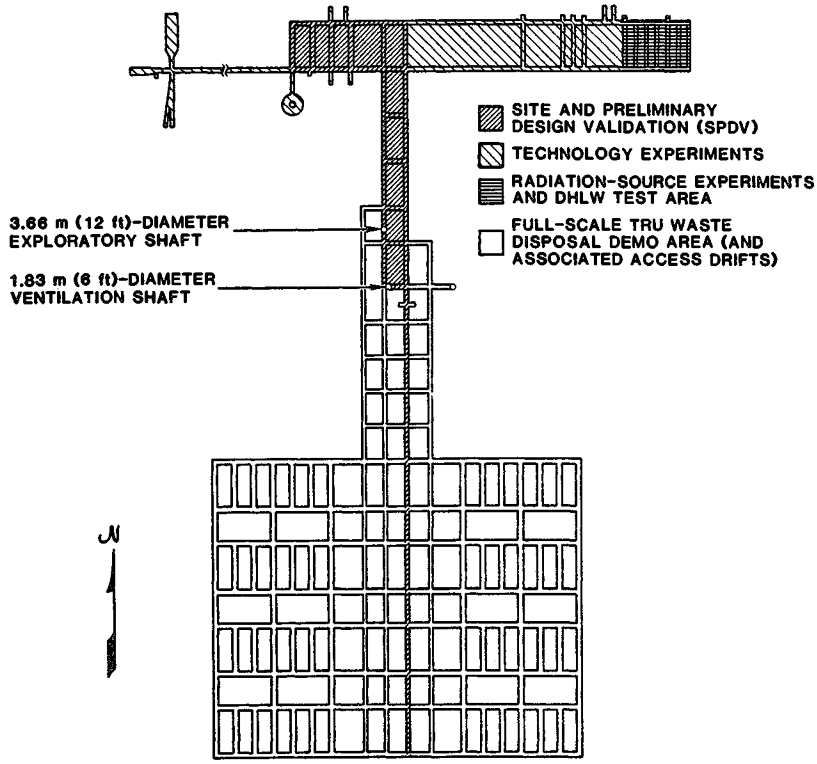

Fig. 1. WIPP Underground Layout