

**Salt Disposal Investigations to Study Thermally Hot Radioactive Waste In A Deep Geologic Repository in Bedded Rock Salt - 12488**

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**ABSTRACT**

A research program is proposed to investigate the behavior of salt when subjected to thermal loads like those that would be present in a high-level waste repository. This research would build upon results of decades of previous salt repository program efforts in the US and Germany and the successful licensing and operation of a repository in salt for disposal of defense transuranic waste. The proposal includes a combination of laboratory-scale investigations, numerical simulations conducted to develop validated models that could be used for future repository design and safety case development, and a thermal field test in an underground salt formation with a configuration that replicates a small portion of a conceptual repository design.

Laboratory tests are proposed to measure salt and brine properties across and beyond the range of possible repository conditions. Coupled numerical models will seek to describe phenomenology (thermal, mechanical, and hydrological) observed in the laboratory tests. Finally, the field test will investigate many phenomena that have been variously cited as potential issues for disposal of thermally hot waste in salt, including buoyancy effects and migration of pre-existing trapped brine up the thermal gradient (including vapor phase migration).

These studies are proposed to be coordinated and managed by the Carlsbad Field Office of DOE, which is also responsible for the operation of the Waste Isolation Pilot Plant (WIPP) within the Office of Environmental Management. The field test portion of the proposed research would be conducted in experimental areas of the WIPP underground, far from disposal operations. It is believed that such tests may be accomplished using the existing infrastructure of the WIPP repository at a lower cost than if such research were conducted at a commercial salt mine at another location.

The phased field test is proposed to be performed over almost a decade, including instrumentation development, several years of measurements during heating and then subsequent cooling periods, and the eventual forensic mining back of the test bed to determine the multi-year behavior of the simulated waste/rock environment. Funding possibilities are described, and prospects for near term start-up are discussed.

**INTRODUCTION**

Previous salt repository studies and operations have been adequate to demonstrate safe disposal of transuranic (TRU) waste in salt. However, for thermally hot waste, there are gaps in the experimental data that may be filled by research proposed under what is called "Salt Disposal Investigations" (SDI) described in this paper. The

developmental history of the SDI management proposal began in 2008 when DOE assessed the need for a second repository to augment the proposed Yucca Mountain Project. As a part of that process, the DOE Office of Nuclear Energy (DOE-NE) funded a scoping study for the feasibility and efficacy of a future contemplated comprehensive repository in salt, with the DOE-EM Carlsbad Field Office (CBFO) and its science and operations contractor organizations providing support.

The final report of the scoping study [1], completed in 2011, provided a proof-of-principle layout and operational strategy for a repository that would meet the combined disposal needs for all reprocessed high-level waste, associated low-level waste, and greater-than-Class-C (GTCC) wastes that would result from a national recycling policy for the entire current commercial nuclear power industry for the next one hundred years. The report pointed toward a near-term science-based program to gain public confidence and provide a regulatory compliance framework that would close gaps in our current knowledge for salt repositories. To augment the SDI proposal, DOE-EM requested a formal and comprehensive compilation of all previous work in salt, current status, and additional science necessary to fill gaps and extend the current understanding of heat generating waste disposal. The resulting report [2], coupled with the referenced scoping study, provide the primary basis for work proposed in the SDI proposal.

Directed laboratory and field research can help reduce uncertainties regarding thermally driven processes involved with decay storage and disposal in salt and increase technical understanding for those potential missions. The research program proposed would directly test a disposal arrangement that balances heat loading with waste and repository temperature limits. It would fill information gaps in current knowledge of the thermomechanical, hydrological, and chemical behavior of salt and wastes disposed in salt and form the technical foundation for design, operation, coupled process modeling, and performance assessment of future salt repositories for heat-generating nuclear waste.

A management proposal to conduct SDI, originally developed in February 2010, was revised in March 2011 at the request of DOE Headquarters to reflect efficiencies and cost savings realized if the test program were to be conducted in the WIPP underground and not in an existing commercial salt or potash mine. WIPP is an operational disposal facility permitted by the New Mexico Environment Department for disposal of hazardous (mixed) waste and certified by U.S. Environmental Protection Agency for radioactive waste disposal. It is managed by the Carlsbad Field Office (CBFO) within the DOE Office of Environmental Management (DOE-EM). As such, proposed activities in this proposal would be performed in accordance with applicable WIPP regulatory requirements. This will ensure that the proposed research will not impact disposal operations or long-term repository performance of the WIPP facility.

The use of the WIPP underground for the field test portion of SDI would realize significant cost savings by avoiding development and installation of a research program at some other existing salt or potash production mine of similar depth. Of course, there remain substantial costs associated with performance of SDI, as delineated in the

management proposal to perform the tests in WIPP. The area to the north of the access shafts (far north of waste disposal operations) is already configured with electrical power and fiber optic cable to service basic science experiments. Additionally, an existing trained workforce, mining infrastructure, nuclear safety bases, and a quality assurance program make the field test component of the SDI at WIPP cost appreciably less while supporting a more defensible experiment compared to bringing these essential elements of a field test to a commercial mine.

## **WHY BEDDED SALT?**

Ten years of successful operation of the WIPP have demonstrated the fiscal and operational efficiency of salt mining and defense TRU waste disposal. Salt investigations in the United States and Germany support the concept of salt disposal for heat-generating waste as well; however, there are some gaps in our knowledge base for the mechanical behavior of salt and the hydrologic and chemical behavior of brine at higher temperatures, as well as how salt interacts with waste constituents at higher temperatures. Heat management is an overriding consideration in repository layout, and the very act of balancing the heat load underground creates ample volume for disposal of non-heat generating wastes such as GTCC and low-level radioactive waste. Furthermore, depending on the results of this testing program and accompanying performance assessment analyses, direct disposal of calcined or other mineralized forms of waste, or other cost-effective changes to upstream processing, might be found acceptable, especially so if wastes were exempt from Land Disposal Restrictions as is the case for TRU waste at WIPP.

The positive attributes of salt that make it an ideal medium for disposal and isolation of hazardous, toxic, and radioactive materials have been recognized for over 50 years [3]. As briefly discussed below, the attributes of salt are collectively important to its isolation capability and essentially summarize the safety case for any generic salt repository.

1. Salt can be mined easily. Salt has been mined for millennia. A wealth of underground experience, including TRU waste disposal operations at WIPP, demonstrates that large-scale, safe mining can be conducted in salt.
2. Salt flows around buried material and encapsulates it. Salt will slowly deform to surround other materials, thus forming a geologic barrier that isolates waste from the environment, without resort to engineered barriers. Creep or viscoplastic flow of salt has been well characterized for many applications. Research in the United States, coupled with international collaborations, has played a significant role in development of this technical understanding.
3. Intact salt is essentially impermeable. The very existence of a salt formation millions of years after deposition is proof that fresh water has not flowed through the rock. Established values for permeability of intact salt come from many industry applications, such as the large-scale storage of oil and gas in solution-mined salt caverns. The permeability of intact salt is essentially too low to measure using traditional hydrologic and reservoir engineering methods. In

undisturbed and healed salt, brine water is not able to flow to waste at rates that would lead to significant radionuclide mobilization and transport.

4. Fractures in salt are self-healing. In terms of disposal, one of the most important attributes of salt as an isolation medium is its ability to heal damaged areas. Damage recovery is often referred to as “healing” of fractures. The healing mechanisms include microfracture closure and bonding of fracture surfaces. Evidence for healing of fractures in salt has been obtained in laboratory experiments and through observations of natural analogs. Fracture healing can readily restore disturbed salt to a low permeability, as noted above.
5. Salt exhibits a relatively high thermal conductivity. Thermal conductivity of natural rock salt under ambient conditions is approximately 3-5 times higher than other potential host geologic media like crystalline rock or clay. A relatively high thermal conductivity is a positive attribute in a salt repository for nuclear waste because the heat is rapidly dissipated into the surrounding formation.
6. Suitable salt formations exist in wide geographic distributions. There are multiple locations with stable geologic salt formations within the 48 contiguous states (see Figure 1) that could host a repository. Bedded salt is preferred over domed salt due to the inherently larger areas contained in the bedded geologic salt formations, which leads to flexibility in accommodating potentially long periods of repository operations. In addition, salt formations have existed for millions of years in non-seismically active areas.

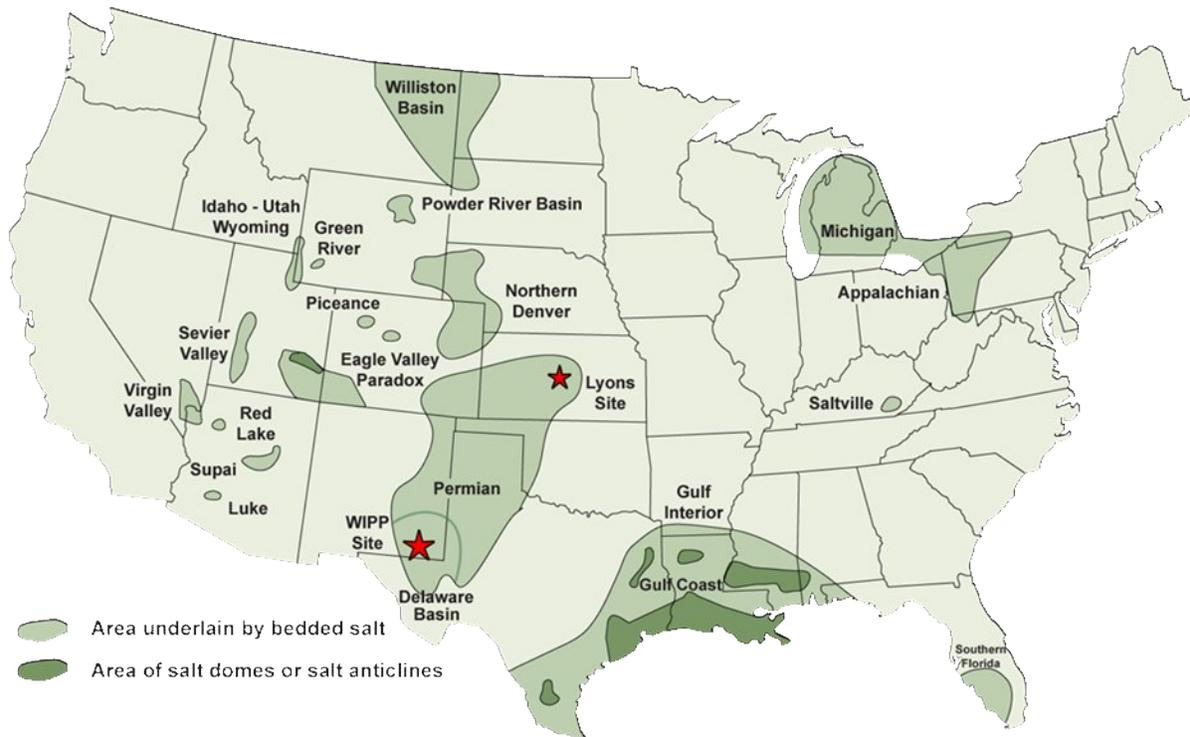


Fig. 1 Salt formations in the US

Salt formations were actively studied in the US for repository applications from the late 60's until the Nuclear Waste Policy Act Amendment eliminated the bedded salt site in

the panhandle of Texas from consideration as the civilian repository for spent nuclear fuel and high level waste. On the other hand, salt repository studies actively continued in Germany through the present time. In a global sense, mechanical, thermal, and hydrological properties of salt formations are fundamentally similar. In the early years of various site investigations, basic properties of many salts were measured. Many of the other basic phenomena, such as dilatant response and plastic deformation mechanisms, have commonality across a wide range of salt formations around the world. These points are made to emphasize that the fundamental studies encompassed in the SDI proposal would be applicable to salt repository studies at essentially any location.

### **Why Study Bedded Salt at Higher Temperatures?**

Laboratory and field studies of intact salt and crushed salt and the chemical interactions of salt with waste packaging, waste forms, and waste constituents received a considerable amount of attention in the 1980s. However, the upper temperature limit for the thermomechanical intact salt tests has been about 200°C, and crushed salt and chemical interaction tests have been conducted predominantly at room temperature [2]. These past studies have been more than adequate to demonstrate that disposal of TRU waste in salt is safe and efficient. However, for thermally hot waste there are gaps in the experimental data that would be addressed by the SDI management proposal. The proposed research, development, and demonstration of salt efficacy will help support evaluation and development of a potential salt repository that could readily isolate very large quantities of both thermally hot and cold nuclear waste material, a key component of a safe and secure nuclear future for the nation.

### **PROJECT MANAGEMENT, QUALITY ASSURANCE, AND SAFETY**

The overall management of the work proposed within the SDI project would be through CBFO. The CBFO defines quality requirements through a Quality Assurance Program Document (QAPD), similar to that used for the WIPP program. The SDI QAPD describes an American Society of Mechanical Engineers Nuclear Quality Assurance 2008 Edition (NQA-1) compliant QA program for the science-based studies concentrating on high thermal loading effects in bedded salt.

The Los Alamos National Laboratory's Carlsbad Operations (LANL-CO) office has been proposed to function as the project management organization, responsible for day-to-day test management and coordination, similar to a successful model used at the Nevada Test Site and the Yucca Mountain Project, ensuring that all test-related information and data activities are consistent and focused. In its management capacity, LANL-CO would report to the CBFO Project Manager.

Sandia National Laboratories (SNL), LANL (and potentially other scientific entities) are expected to provide Principal Investigators to ensure the test is as productive, integrated, and efficient as can be achieved.

The WIPP Management and Operating Contractor would provide engineering, construction, and test support personnel to provide for the test bed (e.g., drift mining, borehole coring, electrical, and ventilation) and aid in test installation.

## **PROPOSED RESEARCH PROGRAM**

The proposed research program would substantially enhance knowledge of the behavior of thermally hot nuclear waste in salt and provide fundamental data for model validation and evaluation of concepts for disposal in salt [2].

The program has been proposed in six elements:

1. Laboratory Chemical, Hydrologic, and Material Studies; Laboratory studies will establish the key factors that control brine migration, radionuclide solubility, and mobility at elevated temperatures. In addition, material interaction data will be obtained that can be used to evaluate waste forms.
2. Coupled Process Modeling; Prediction of the behavior of the field test will initially be made using the best-available models of thermomechanical behavior, including creep, damage, healing, reconsolidation, and coupled processes. Improvements have been identified for certain elevated temperature constitutive models and brine availability including vapor phase transport. Some of the thermomechanical information will be gleaned from laboratory studies and validated as the field test progresses. The models will be updated using data collected in this study to continuously improve and validate predictive capability. Thus, a rigorously developed modeling capability will be available for use in future design and performance assessment activities for disposal in salt.
3. Functional and Operating Requirements and Test Planning; The field test will require a description of functional and operational requirements (F&OR). The work to develop the F&OR document was funded in FY11. Detailed test plans will be developed, reviewed, and delivered in FY12.
4. Laboratory Thermal and Mechanical Studies to Support the Field Test; Elevated salt temperatures will cause accelerated salt-creep deformation, which leads to a more rapid encapsulation of the waste. Laboratory studies on the salt from the field-test site are designed to examine intact and crushed salt at the high temperatures expected for alcove disposal.
5. Field Test Installation and Operation; Benefits accrue from using the existing infrastructure at WIPP, with its well characterized rock salt. The field test will provide full-scale data for the models used to predict behavior of salt and brine at elevated temperatures. The proposed test is designed to push the limits of salt heat loading and waste temperature. One important field test design criterion is high thermal loading. If the test proceeds at a design thermal load of 40 watts per square meter, the test bed will experience temperatures in excess of 160°C in the salt mass, above where most data have been acquired to date. Steady state creep rate at the WIPP disposal horizon accelerates one order of magnitude for each increase of approximately 12 degrees Centigrade. The

affected salt near the heater is expected to flow rapidly and perhaps decrepitate (i.e., burst owing to the vapor phase pressure of fluid inclusions). Upon review of this very aggressive temperature limit, a decision to modify the test temperature in the formal review of the test configuration will be made. However these considerations will be informed early by the laboratory testing. Experimentation in the laboratory will also present significant technical challenges in terms of instrumentation survival and data acquisition. As the laboratory thermomechanical testing proceeds in advance of the field test, laboratory experience will greatly inform the field-test team. In addition, the field test will produce data directly applicable to a potential repository by testing a disposal arrangement.

6. International Collaboration; Collaboration with the European Union countries (particularly Germany) will avail technical staff of the latest international developments in salt repository sciences.

## **LABORATORY THERMAL MECHANICAL STUDIES TO SUPPORT FIELD TESTS**

Laboratory studies of salt are proposed and described in the following sections. The laboratory studies are intimately related to the needs of the modeling program. Experiments to evaluate consolidation of hot, dry, run-of-mine salt, will yield a stress/temperature/porosity function needed for modeling the disposal proof of principle. In addition, an assessment of thermal conductivity as a function of porosity is needed to properly account for the transient evolution of the disposal area. The understanding of deformational phenomenology of exceptionally hot uniaxially tested intact salt is fundamentally important before final design parameters are assigned for the disposal concept field test. These thermomechanical (TM) laboratory results are essential for modeling and therefore need to be conducted as early in the program as possible. These TM inputs are used directly for modeling the proof-of-principle disposal concept, which includes liberation of accessible brine.

### **Intact Salt Studies**

Test conditions will push the threshold of laboratory experience on natural salt. It will be important to preserve flexibility in the test plan to change the preliminary test conditions if results warrant it. The intact salt will be tested in an unconfined condition at a constant axial strain rate using solid cylinders. Uniaxial stress loading will continue until specimens exhibit either failure or extreme deformation (~20% strain). It is well known that salt deformation, even at room temperature, is dominated by plastic deformation mechanisms. Crystal plasticity will be greatly enhanced as temperature increases, such that extensive plastic deformation will accompany fracture formation. As a preliminary basis of estimate, a total of nine tests will be conducted comprising a triplet of tests at each of three temperatures: 200°C, 250°C, and 300°C.

Inelastic creep processes will dominate the deformation of the specimens even in a quasi-static load application, with the creep response being ever more pronounced as the temperature increases. Rather than specimen failure, extreme deformation is

expected to terminate testing. The tests at 200°C will overlap with historical databases and provide a point where predictive models based on those databases can be checked for the current work. The tests at temperatures above 200°C will provide new data so that extrapolation outside the actual test database may not be necessary. The field test (and actual alcove disposal) is expected to involve temperatures much greater than 200°C (at the heaters), thus this high-temperature research is needed for the design and evaluation of the in situ experiment. All testing will be performed under an approved test plan developed in accordance with appropriate QA requirements discussed earlier in this management proposal.

### **Crushed Salt Studies**

The laboratory tests on crushed salt include consolidation as a function of stress and temperature and thermal conductivity as a function of bulk density and temperature. Here “crushed” salt means run-of-mine salt (potentially sieved to separate out large aggregate). Consolidation of run-of-mine salt can be performed in two ways: either using an oedometer arrangement or an isostatic pressure vessel. Thermal conductivity of the backfill salt will be measured on reconsolidated salt specimens produced during the consolidation studies. The thermal properties will be measured over a temperature range from room temperature up to 300°C and at a variety of porosities.

Thermal conductivity tests will be performed over a temperature range from room temperature to 300°C at known values of fractional density (porosity). The specimens for the thermal conductivity tests will be created in a manner similar to the way uniaxial consolidation tests are conducted. The major difference in the thermal conductivity specimen creation test will be that the test will be terminated at specific targeted values of fractional density. Additionally, the specimens might have to be sized differently than the mechanical test specimens for thermal conductivity test purposes.

### **LABORATORY HYDROLOGIC, CHEMICAL, AND MATERIAL STUDIES**

During the field test, it is anticipated that the underground salt environment will be heated to temperatures for which current experimental data do not exist, especially for crushed salt configurations. Two interrelated components of the system involve the nature and fate of brine as well as the geochemical interactions of the salt, brine, engineered materials, and radioactive waste. Understanding potential mobilization of native brine is essential to establish the evolution of the underground setting of the disposal concept. Migration of small amounts of water present in fluid inclusions within the intact salt, as well as the potential liberation and transport of brine derived from dehydration of hydrous minerals within interbeds of a halite deposit, must be characterized to assess the basic amount of brine available to the system and its ability to influence deformational processes, such as fracture healing and granular salt consolidation. In addition, as the assumed potential carrier of radionuclides, the brine source and transport represent essential components of the repository source term for scenarios in which brine-waste interactions must be evaluated.

Closely related to the source and transport of brine is the chemical and material behavior of the brine/salt/engineered materials/waste form system. Laboratory studies will establish the key factors that control radionuclide solubility and mobility at elevated temperatures. Data obtained will be used to fill knowledge gaps in models for radionuclide release for the range of hypothesized intrusion conditions that could be encountered in the disposal of thermally hot waste in a salt repository. In addition, material interaction data from both the laboratory studies and the field test site will be analyzed, providing data that could be used to assess the compatibility of various waste forms, if warranted.

Investigations proposed include:

- Hydrologic Behavior
  - brine migration
  - clay dehydration and phase transformation studies
- Chemical and Material Studies
  - thermodynamic properties of brines and minerals at elevated temperatures
  - repository interactions with waste container and constituent materials
  - effect of temperature on radionuclide solubility in brine
  - radionuclide oxidation distribution and redox control at elevated temperatures

## **COUPLED PROCESS MODELING**

Prediction of the thermomechanical and hydrologic response of the in situ experiment will initially be made by benchmarking calculations using the best-available codes and models. It is anticipated that at least the two primary national laboratories involved with SDI will participate in the benchmark calculations, and international collaborators will be invited to model the benchmark as well. Benchmarking computational capability is common practice in repository programs, and was done on the WIPP program many years ago, on an international parallel calculations exercise, and more recently by the European Commission. The benchmark parameters will be established by a technical team. The benchmark modeling cases will assume that the initial modeling structure and the parameter values are understood and certain. However, it is known that there are differences in the constitutive models adapted for the state-of-the-art codes. The performance will be assessed in the benchmark exercise. The benchmark model will be used to inform the field test personnel with regard to placement of instrumentation and sample coupons, as well as establish the data quality objectives for the main test parameters.

## **FIELD TEST PROOF OF PRINCIPLE**

This section describes a preliminary, high-level plan to conduct a field test in salt to evaluate its behavior under thermal loads representative of those that would be experienced if HLW were disposed in salt. To set the stage for this proposed field test

program, first, the motivation and the basis for selecting the geometry and conditions of the test is described. One of the most important elements affecting the design of a HLW repository is heat management. A disposal safety case, properly conceived and elucidated, relies on well-understood processes attesting to the stability and durability of the geologic barriers to radionuclide migration over geologic time scales. Perturbations caused by the installation of a mined opening or the emplacement of waste must be carefully considered. As such, the decay heat from the waste places limits on the maximum possible area density of waste, with a significant impact on utilization efficiency of the subsurface facility. Consequently, the management of waste before it is emplaced in the repository, and the configuration of waste packages underground, must be conducted such that critical thermal design criteria are met.

To conduct meaningful, focused research in geologic disposal, an appropriate starting point is a disposal concept describing the physical configuration of wastes in the underground, and the operations that would be conducted to load the repository. For salt, the favored approach is to select a disposal concept that is reasonably bounding in terms of local and area-average heat load, is feasible and efficient operationally, and is likely to result in a solid safety case provided that issues identified as uncertainties are addressed. A study of a generic salt repository for disposal of thermally hot HLW forms the basis for the disposal concept described. That study [1], which proposed a conceptual design of a repository from a future closed fuel cycle producing large quantities of heat-generating borosilicate glass HLW, presented a subsurface and surface facility design and disposal strategy that, in principle, can be practically realized using proven mining operations. The study assumed that waste with significant radionuclide loadings, including Cs, Sr, and other heat-generating elements, would be buried with minimal decay storage, thereby providing an aggressive, bounding case with respect to the thermal load.

One key component of the conceptual emplacement in [1] was the use of “in-alcove” emplacement versus the “borehole” emplacement model employed at WIPP for remote handled TRU waste today. The in-alcove waste-disposal concept innovatively balances safety, ease of operation, and heat management. This configuration is different than the configurations tested at Lyons, Kansas; Avery Island, Louisiana; or the thermal/structural interaction tests at WIPP. In these earlier tests, live nuclear waste packages (at Lyons) and electrical heaters (at WIPP, Lyons, and Avery Island) were placed in vertical boreholes drilled into the floor of the mine.

The field test component of SDI will include investigation of the in-alcove emplacement concept, and is planned to consist of multiple alcoves containing an electric heater to simulate a disposed waste package [4]. An electric heater will be placed on the floor near the back of the alcove and covered with crushed salt. Thus, one waste-disposal configuration for the field test is a full-scale mock-up, with heat loads and spacing that are intended to bound thermal conditions for disposal operations. The field test, laboratory tests, and modeling activities are designed to produce data directly applicable to a potential repository, to reduce the uncertainty of current predictive

models, and to improve the scientific bases of the models. Figure 2 illustrates the general layout and architecture of the field test area within the WIPP underground.

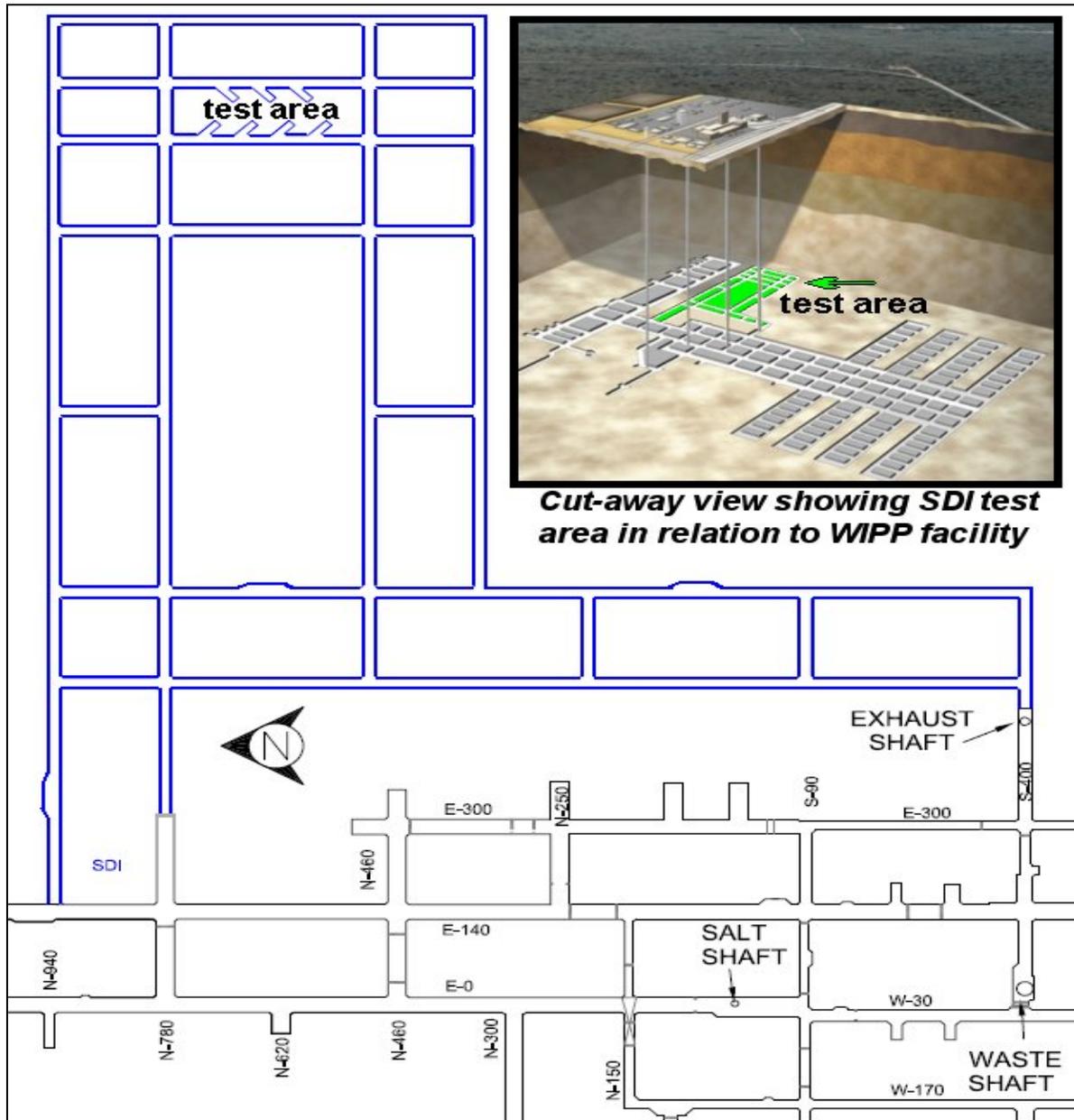


Fig. 2 Field test area location of SDI, showing extent of required mining in relation to the existing WIPP underground configuration

Another potential emplacement concept that may be tested is referred to as “in-drift” emplacement. If the heat load distribution is not as important as required by large separation between highly loaded canisters, one can imagine simply placing low-heat packages along the disposal drifts, without regard to large lateral separation. The moisture balance and migration in a salt repository could be significantly different

between cases of in-drift and in-alcove emplacement concepts. The in-drift configuration could allow more moisture to be removed from the disposal system via ventilation during ongoing operations.

Field tests will incorporate measurements of temperature changes imposed on the intact salt surrounding the alcove (roof, floor, and pillars) and run-of-mine salt placed as backfill over the waste. Closure and entombment processes will be measured directly by various deformation gauges, as well as post facto forensic reconnaissance. Hydrologic effects will be determined through the monitoring of moisture/brine movement in and around the test alcoves, as well as down-drift in the exhaust air. In addition, chemical effects on various metal coupons and radionuclide analog elements will be assessed during the forensics stage. The test bed is expected to see temperatures in excess of 160°C in the salt mass. The field tests will be complemented by laboratory tests on dry mine-run salt to determine deformation characteristics at elevated temperatures (200–300°C) and on intact salt specimens to obtain creep rates above 200°C. The pre-test and post-test chemistry and environmental parameters will also be evaluated and compared to laboratory test results under more carefully controlled environmental conditions. The underground experiment will measure the imposed transient temperature field, the accelerated deformation in the intact salt and backfill, and the movement of moisture/brines in the salt.

## **REGULATORY APPROVAL**

WIPP waste receipt and disposal operations are conducted within two primary regulatory frameworks. The long-term repository performance and potential for exposure to radioactivity during the waste emplacement phase is regulated by the Environmental Protection Agency (EPA) under the national repository disposal standards promulgated in 40 CFR Part 191 and the associated criteria established in 40 CFR Part 194. The second major regulatory regime is the Resource Conservation and Recovery Act (RCRA), which is administered by the State of New Mexico Environment Department, with operations permitted under the provisions of a Hazardous Waste Facility Permit issued by the State.

DOE was required to demonstrate that the SDI field test could be safely performed at WIPP without impact to long term repository compliance. That demonstration was submitted to the EPA as a planned change notice in July 2011, and included calculations of the impact of the bounding heat injection. EPA evaluated the request and granted conditional approval to begin mining the field test area shown in Figure 2 in November 2011. Because final field test plans must await initial laboratory and modeling results, EPA requested that DOE submit those final field test plans for its review prior to beginning actual heat injection underground. Because the SDI field test will incorporate no hazardous materials or impact the safe operation of the WIPP facility, no modification of the hazardous waste facility permit was sought from the State of New Mexico Environment Department. However, DOE did consult with the State to ensure it and WIPP stakeholders were notified of DOE's intent to conduct the field test portion of SDI at WIPP.

## **COST AND SCHEDULE**

The total SDI project cost is estimated to be approximately \$43M over 10 years, which includes mining and engineering labor as existing WIPP resources and infrastructure; therefore, those total costs are not included in the SDI specific budget necessary to complete the work. Consumables and equipment, however, are included as direct costs in the \$43M estimate.

### **FY11 - Completed Milestones**

- Completed the SDI Management Proposal
- Completed a Test Plan for laboratory testing for crushed salt in the laboratory to measure thermomechanical behavior across a variety of temperature, stress, and porosities
- Initiated laboratory tests on crushed salt
- Developed an NQA-1-compliant Quality Assurance Program Document and associated procedures
- Completed the F&OR document for the field test

### **FY12 - Test planning, initial mining and laboratory studies**

- Begin elevated temperature tests on intact salt in the laboratory to measure thermomechanical behavior across a variety of temperatures and stresses
- Continue the laboratory tests on crushed salt
- Develop and review the detailed field test plan with equipment lists, instrumentation and borehole layouts, data quality objectives, etc.
- Comprehensively evaluate existing and available information from past thermal experiments
- Develop the criteria for the underground test design and layout
- Begin mining the underground access drifts to the test bed location
- Begin installing ventilation control and power distribution
- Write test plan for laboratory studies of water liberation and brine migration in salt
- Begin measuring the thermodynamic properties of brines and minerals at elevated temperatures in the laboratory
- Develop a test plan and begin measuring the effect of temperature on radionuclide solubility in the laboratory
- Develop a test plan and begin studying repository interactions with waste container and constituent materials in the laboratory

### **FY13 - Initial studies and evaluate and use coupled multiphysics modeling capability for field test configuration and analysis**

- Continue development of fully coupled TM(H) code and model for field test analysis.
- Continue laboratory thermomechanical testing and chemistry experiments
- Conduct laboratory studies of water liberation and brine migration
- Develop test plan for intact core testing in the laboratory
- Procure test equipment and instrumentation for the field test

- Develop work control and safety basis for the field test
- Complete mining of the underground access drifts
- Develop the documented safety analysis for the field test
- Mine the field test bed

#### **FY14 - Field test implementation**

- Core instrumentation boreholes
- Implement the field test equipment, including data collection equipment and fiber optic communication equipment
- Investigate salt properties of test bed location
- Preparedness assessment for field test start and baseline measurements
- Continue laboratory thermomechanical testing and chemistry experiments
- Conduct laboratory studies of water liberation and brine migration
- Continued development of fully coupled THMC code and model for field test analysis

#### **FY15 – FY20 - Conduct the proof-of-principle field test**

- Heating start on field test – FY 15
- Investigate thermal effects on intact salt in situ
- Develop a full-scale response for dry crushed salt
- Observe and document fracture healing in situ
- Track moisture movement and vapor phase transport in situ
- Complete laboratory thermomechanical testing and chemistry experiments
- Complete laboratory studies of water liberation and brine migration
- Cool-down of field test by FY 19
- Post-test forensics, mine-back and post-test coring in FY 19 and FY 20
- Complete the final test and data reports
- Develop calibrated, coupled TM(H) model

### **CONCLUSIONS AND SDI STATUS**

Mining of the access drifts required to create the test area in the WIPP underground began in November 2011. Because this mining uses existing WIPP infrastructure and labor, it is estimated to take about two years to complete the access drifts. WIPP disposal operations and facility maintenance activities will take priority over the SDI field test area mining.

Funding of the SDI proposal was still being considered by DOE's Offices of Environmental Management and Nuclear Energy at the time this paper was written, so no specific estimates of the progress in 2012 have been included.

### **REFERENCES**

1. Carter, J.T., F.D. Hansen, R. Kehrman, and T.A. Hayes, 2011, [A Generic Salt Repository for Disposal of Waste from a Spent Nuclear Fuel Recycle Facility](#). SRNLRP-2011-00149. Savannah River: Savannah River National Laboratory.

2. Hansen, F.D., and C.D. Leigh, 2011, Salt Disposal of Heat-Generating Nuclear Waste, SAND2011-0161, Albuquerque: Sandia National Laboratories.
3. National Academy of Sciences and NRC, 1957, Disposal of Radioactive Waste on Land, Report by the Committee on Waste Disposal, Division of Earth Sciences, The National Academies Press, Washington, DC.
4. Robinson, B., N. Elkins, and J. Carter, 2012, Development of a U.S. Nuclear Waste Repository Research Program in Salt, Accepted for publication in Nuclear Technology, 2012.