HISTORIC TESTING RELEVANT TO DISPOSAL OF HEAT-GENERATING WASTE IN SALT

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Significant laboratory and in situ testing has been conducted by both the United States and Germany on salt disposal of heat-generating radioactive waste. Coupled simulation capabilities recently developed in other fields are now being applied to repository design and performance confirmation. New efforts are underway to benchmark this latest generation of numerical models, requiring quality validation datasets. Datasets associated with historic high-level waste (HLW) field experiments at the Waste Isolation Pilot Plant in New Mexico, Avery Island in Louisiana, Asse II in Germany, and Project Salt Vault in Kansas should be considered before constructing new experiments.

We constructed an online bibliographic database using the web reference database (Refbase) distribution to contain references to reports, and conference papers, along with associated electronic copies of reports and associated data. The database was populated using publically available Department of Energy sources and project-specific archives scanned for this project. The browser-based database facilitated an extensive collaborative review of experiments in geologic salt – primarily concerning heated salt that may be applicable to modern code validation efforts.

We summarize historic in situ tests conducted in geologic salt, focusing on heated salt creep, heated brine migration, and crushed salt reconsolidation. We propose several candidate thermal, mechanical, and hydrological validation datasets for salt behavior under repository conditions.

I. DATABASE

This activity included the design, selection, implementation, and population of an online bibliographic database. This database was initially populated from several US Department of Energy (DOE) sources (including Sandia National Laboratories Technical Library, Los Alamos National Laboratory Library, and the DOE Office of Science and Technical Information (OSTI) Information Bridge http://www.osti.gov/bridge/ and Energy Citations Databases http://www.osti.gov/energycitations/), and was supplemented during the review process from several external sources (including the European Union Bookshop http://bookshop.europa.eu/). Electronic copies of reports are attached to entries whenever available. The records in the database were reviewed and ranked by their potential relevance to current salt research and development research related to disposal of heat-generating waste.

The Salt Investigations Technical Expansive Database (SITED) collectively refers to the database software, the web-based interface, and the server used to deliver both the web pages and attached files. The open-source web reference database (Refbase – www.refbase.net) was chosen because it has a simple, intuitive, and powerful interface and best satisfies the design criteria, given the project time and budget constraints.

The database design had several key requirements that led to the selection of the Refbase database software. The requirements for the database and its interface included the ability to:

- access the interface from outside Sandia National Laboratories (SNL) via the public internet;
- allow creation or editing of database records by authorized personnel;
- allow searching/querying existing records by authorized personnel (potentially a different group than those allowed write access);
- allow bulk record import from primary sources;
- allow attachment of multiple files (e.g., PDF, ASCII text, or data) to each record; and

Several commercial and free open-source alternatives were considered. Refbase was chosen because it fulfilled the above requirements and was freely available as source code (PHP scripting language) for customization to our specific needs when necessary. The database is hosted and the web interface is served from an SNL webserver (https://sited.sandia.gov/sited), which is accessible both inside the SNL intranet, and from any computer with a

modern web browser and internet access. The landing page for the database is publicly accessible, but SITED requires explicit access permissions from the author to read or edit the database.

II. SITING HISTORY OF SALT REPOSITORIES

The history of siting nuclear waste repositories around the world has been complex, due to the political nature of the topic. We briefly summarize the siting history of salt nuclear waste repositories, as it relates to the research, which has been conducted in support of this overall mission.

Pierce and Rich[1] presented a summary of late 1950s US Geological Survey (USGS) regional salt characterization work, producing reports that included an inventory of US salt deposits. These studies identified four regions as potentially suitable for a salt-based nuclear waste repository. The salt regions of interest were:

- Salina Group bedded salt of the Michigan and Appalachian basins;
- Gulf Coast domal salt;
- Permian Basin bedded salt of southwestern Kansas, western Oklahoma, western Texas, and southeastern New Mexico; and
- Paradox Basin anticlines, primarily in southeastern Utah and southwestern Colorado.

Johnson and Gonzales[2] later confirmed these results through more detailed studies of salt deposits. Strong public objection and lack of state cooperation prevented any significant characterization or research efforts related to radioactive waste disposal in the Michigan and Appalachian Basins of the northeastern US[3].

Project Salt Vault was a solid waste disposal demonstration in bedded salt performed by Oak Ridge National Laboratory (ORNL) in Lyons, Kansas. The US Atomic Energy Commission (AEC) intended to convert the project into a pilot plant for storage of high-level waste (HLW). Despite these intentions, the Lyons site was abandoned due to nearby solution mining and questionably plugged oil and gas boreholes. With help from the USGS, in 1972 ORNL began looking in the Permian basin for a different disposal site in Texas or New Mexico[3].

Work on the Waste Isolation Pilot Plant (WIPP) project began after the abandonment of the Lyons, Kansas salt repository project with a view to developing a geologic repository for transuranic wastes from the defense program. The WIPP project was discontinued in 1974 in favor of concentrating efforts on a Retrievable Surface Storage Facility. After the demise of that project in 1975, work resumed on WIPP and its scope temporarily expanded to include defense HLW[4].

A location a few miles northeast of the current WIPP site was chosen for further study. ORNL cored two exploratory boreholes through the Permian salt at this location (AEC-7 and AEC-8). SNL became the project lead on the New Mexico salt repository, and undertook a major geological site characterization effort for the Los Medaños area[5]. After early geologic complexities and pressurized brine were encountered in the ERDA-6 borehole, the site was moved southwest to its current location.

Initial WIPP conceptual design involved two waste handling buildings and two waste storage levels, the existing level for transuranic waste and a lower level for defense HLW. By May 1978, as the conceptual design for WIPP was being completed, a revised HLW mission was being developed which included one waste-handling building and experimental (temporary) HLW storage. In the summer of 1979, Congress and the DOE re-designed the WIPP yet again, eliminating the HLW component (and the lower disposal level) altogether[4]. At this point the DOE began the environmental impact statement for WIPP, which was completed in 1981, allowing WIPP site construction to finally begin.

Many salt locations were drilled or sampled as part of a HLW salt repository siting process in the United States[3] from the late 1970s until 1985. These sites often had deep large-diameter boreholes drilled, which provided salt cores used in laboratory creep tests and brine characterization studies. By 1985 the salt repository siting process had narrowed the search down to:

- Palo Duro Basin (bedded salt) in northern Texas (including the Deaf Smith and Swisher sites)
- Paradox Basin (salt anticline) in eastern Utah and western Colorado (including Davis Canyon and Lavender Canyon sites)
- Richton and Cypress Creek Domes in Mississippi
- Vacherie Dome in northern Louisiana
- Oakwood Dome in east Texas

In 1986, the list of potential repository sites was reduced to three sites, including the Deaf Smith, TX site and the two non-salt sites at Hanford, WA and Yucca Mountain, NV. In 1987, the Nuclear Waste Policy Act Amendments called for phase-out of all site-specific HLW activities at all sites other than Yucca Mountain.

III. SALT RESEARCH HISTORICAL SUMMARY

In 1955, the AEC convened an expert panel to investigate options for disposal of radioactive waste. They recommended salt as the best disposal medium, preferring disposal of liquid reprocessing waste directly into salt caverns[6]. Concurrent with this panel's work in

the mid 1950s, researchers at University of Texas investigated the design principle of direct liquid disposal of reactor reprocessing waste into caverns in salt domes for the AEC[7]. They carried out significant laboratory strength, creep, and permeability tests on salt samples at a range of elevated temperatures (up to 410° C) and performed closure measurements in the Grand Saline salt mine, 50 miles east of Dallas, TX.

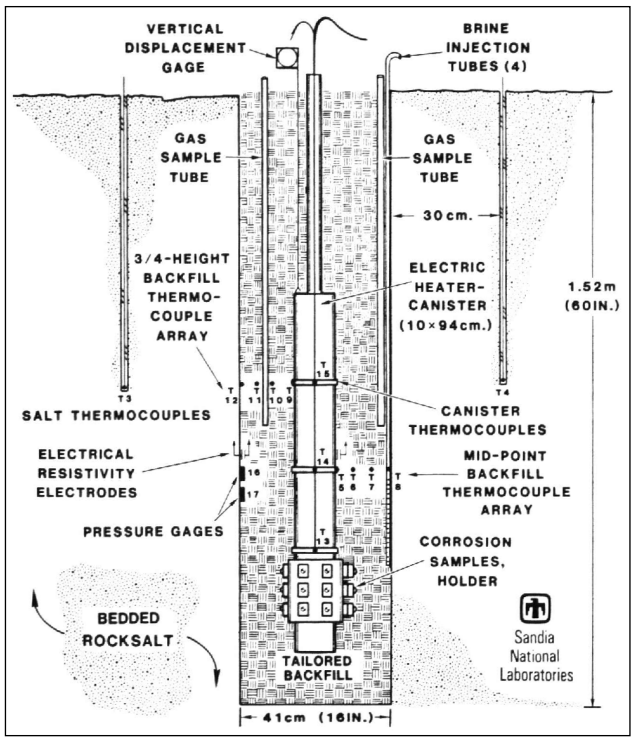

Figure 1. Waste Package test in MCC Potash Mine

Project Salt Vault was the first significant in situ research on disposal of radioactive waste in salt in the United States. This was both a research project and a demonstration of solid HLW disposal. Early Salt Vault tests had shown direct liquid waste disposal in salt to be impractical, due to concerns about vaporization, loss of containment, and waste-rock interactions[3]. In the early 1960s Salt Vault was carried out by ORNL for the AEC in abandoned Carey bedded salt mines in Hutchinson and Lyons, Kansas[8]. From 1965 to 1967, large-scale heater tests were conducted in three sets of seven vertical boreholes, measuring brine inflow to the boreholes and incorporating radioactive sources. Large amounts of brine inflow were observed in boreholes intersecting shale layers (Room 5). The Salt Vault research project also included heated pillar experiments, waste package corrosion studies, and extensive laboratory tests on brine migration and salt creep at elevated temperatures. Once the Lyons site was rejected as a repository location, focus shifted to the Los Medaños area of New Mexico.

In 1975, SNL became the lead laboratory on the southeastern New Mexico disposal project started by ORNL. SNL continued laboratory salt creep testing, begun by ORNL on salt cores collected from the AEC-7 and AEC-8 boreholes[9]. Since limited salt was available for testing from these boreholes, larger samples and tests were sought from the nearby Mississippi Chemical Company (MCC) potash mine, completed in an upper region of the Permian Salado Formation where WIPP was eventually constructed. Instrumentation was installed to monitor creep closure of the potash mine workings, and in situ tests were carried out[10]. In situ tests included closure tests in high-extraction (~90% extraction ratio) areas of the mine, heated brine migration tests, and a suite of six waste package corrosion and backfill consolidation studies (Figure 1).

Laboratory tests began immediately in 1978 on larger salt samples (1-m cylinders weighing 1700 kg each) collected from the MCC potash mine to investigate brine migration and the thermal properties of salt. Salt Block I and II tests determined thermal properties of the bedded potash-bearing salt. These laboratory tests included extensive brine-migration analysis during different heated stages of the tests (Figure 2). Post-test analysis of the salt near the heater showed brine inclusion migration was a small component of the overall brine collected in the heated borehole.

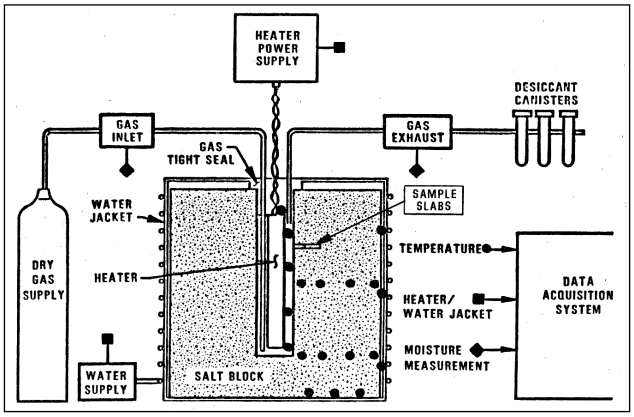

Figure 2. Salt Block II experiment on 1700-kg salt sample

In 1978 in situ heated salt tests began at the Avery Island salt mine for investigation of commercial HLW disposal in salt domes[11]. They performed long-duration (1858 days) heated borehole studies (up to 9.6 kW, see Figure 3), a set of three brine migration experiments (including deuterium-marked tracer studies), gas permeability studies of heated salt, and accelerated borehole closure (corejacking) tests.

Laboratory creep and thermal testing of salt samples continued using core from WIPP, Avery Island, and several candidate salt dome HLW repository sites. The

first underground excavations at the WIPP site were completed in 1981. Site Preliminary Design Validation work by Bechtel continued through 1983, including the first WIPP closure measurements and detailed site geology[12]. SNL's work on the WIPP site included contributing to the site design with Bechtel and the development of a significant in situ salt testing program.

Figure 3. Avery Island Site C Test with 8 Guard Heaters

Portions of the in situ tests at the Avery Island[11] and the MCC potash mine continued through 1984. These locations were not considered potential repository locations, but because of their immediate availability, they were used as testing locations to both refine underground testing techniques and compare the variability of salt properties across different sites.

The three main in situ research programs at WIPP were the Thermal/Structural Interactions (TSI) program, the Waste Package Performance (WPP) program, and the Plugging & Sealing Program (PSP)[13]. The plans for these tests were well documented, numerically simulated beforehand using the best available models, and subject to a rigorous peer-review process. As the test designs were finalized, mining of the first testing area began with Room D in 1984, with the first phase continuing through 1986. While mining progressed elsewhere in WIPP, experimental rooms were instrumented and heaters were installed, with the first in situ heater tests (A and B rooms) turned on in 1985, running to as late as 1990.

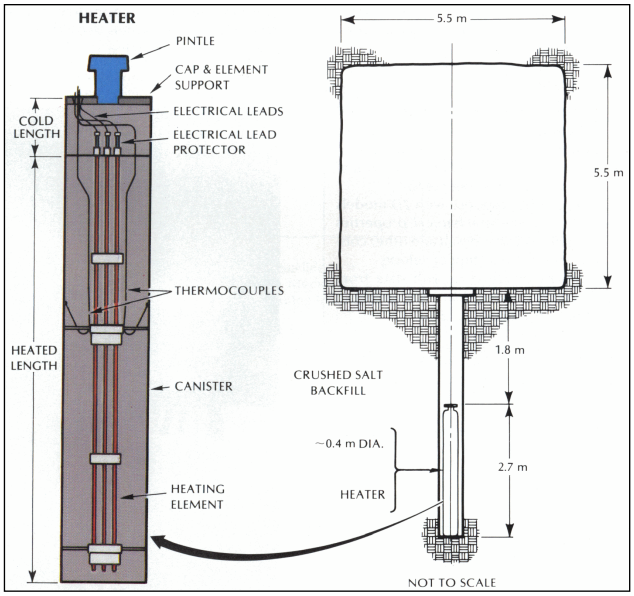

Figure 4. Typical Heater in WIPP TSI Room A and B tests

The tests in Rooms A1, A2, and A3 were designed to replicate the design defense HLW repository, with a heat load of 18 W/m^2. Central Room A2 followed the design layout of heaters (each 470 W, see Figure 4), and Rooms A1 and A3 were "guard rooms" with higher heat loads to re-create the thermal and closure effects of a large repository consisting of many rooms like Room A2 (Figures 5 and 6). Extensive thermal, differential closure, waste package corrosion, brine migration, and heat flux measurements were made during the several years of these tests.

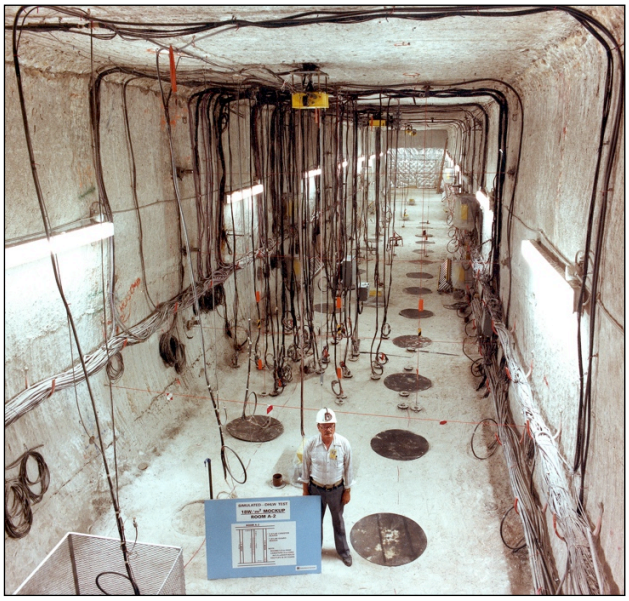

Figure 5. WIPP TSI Room A2 Heater Test

Room B was a single room with much higher heat loads, to develop "overtest" conditions. Heaters in Room B were much higher power, up to 4 kW per canister for the guard heaters (1.5 kW for main heaters).

At the same time the WIPP experimental areas were being excavated, site characterization work was ongoing at the Deaf Smith site in Texas[14]. Although only borehole cores were collected (no shafts were mined), extensive compositional and laboratory creep tests were conducted on the targeted Permian evaporite deposits.

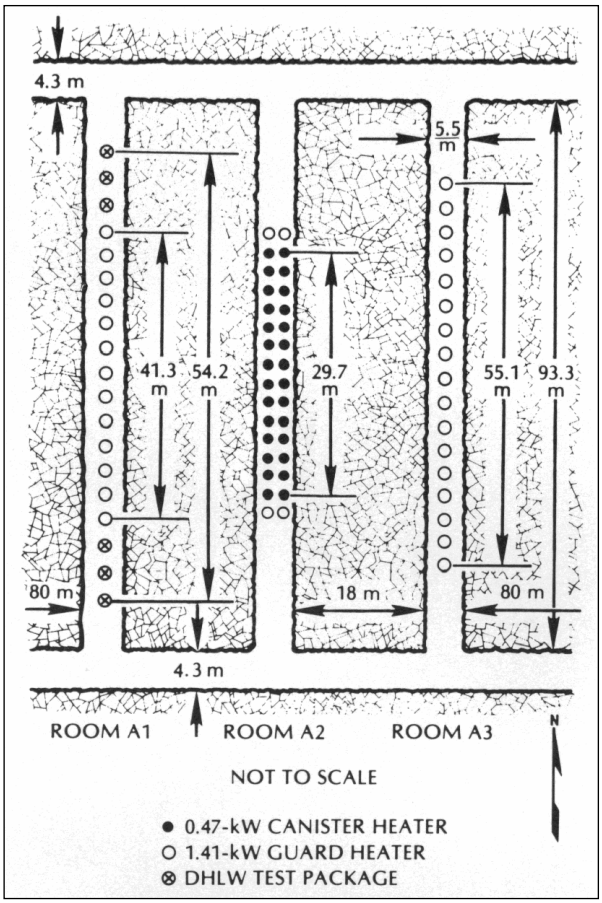

Figure 6. WIPP TSI Rooms A1, A2, and A3 Layout

Heated brine inflow experiments with radioactive sources were also being carried out from 1983 to 1987 at the Asse II facility in Germany[15]. These tests were similar to brine migration tests done at WIPP, except the much lower water content of the domal salt resulted in a much different result. Less than 0.2 liters was collected per borehole during the heated portion of the Asse test (Figure 7), whereas WIPP brine inflow collected over 4 liters in Room A1 boreholes and as much as 35 liters of brine in Room B boreholes.

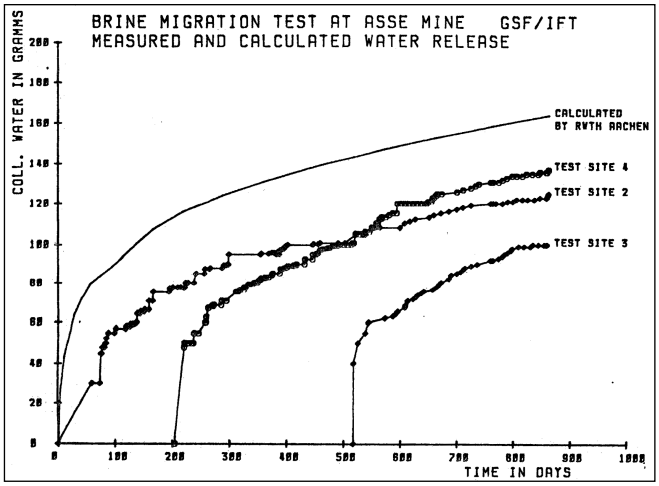

Figure 7. Heated Brine Migration test results at Asse II

After the 1987 amendment to the Nuclear Waste Policy Act, the Deaf Smith site was abandoned and the only US salt research remaining related to heat-generating waste was defense HLW research already ongoing at the WIPP (i.e., TSI tests and DHLW WPP tests) that were now ordered to finish as soon as possible. Salt research related to the WIPP transuranic waste mission continued, including the PSP studies (e.g., large-scale Room Q brine inflow, small-scale mine-by study, and intermediate-scale borehole test).

Drift-scale heated salt tests were conducted at the Asse II facility from 1990 to 1999. These tests were followed up by a significant laboratory testing program (BAMBUS II), dedicated to the post-mortem analysis of the instrumentation and crushed salt around the heated disposal casks[16].

Hansen & Leigh[17] give a recent high-level summary of salt work completed to date around the world. They include a vision for future heat-generating nuclear waste disposal in salt, drawing from SNL's role as lead laboratory on the WIPP, Yucca Mountain, and Strategic Petroleum Reserve projects.

IV. SUMMARY

A large number of in situ tests have been conducted in salt at a half-dozen salt study locations over more than 60 years. Many of the experiments were sophisticated, well-designed, and extensively instrumented. Current and future research into disposal of heat generating waste in salt should carefully examine existing work, both to find data for answering questions, and to learn about experimental design from both the successes and failures of past experimentalists.

We hope the SITED study is useful to other salt researchers, who may contact the author for access to the repository of information. Information and reports continue to be added to the database as they are discovered.

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