WIPP SIMULATED DHLW TESTS: STATUS AND INITIAL IN SITU BACKFILL THERMAL CONDUCTIVITIES

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ABSTRACT

Several series of waste package performance technology experiments for simulated defense high-level waste (DHLW) packages have been emplaced and put into active operation at the Waste Isolation Pilot Plant (WIPP) facility. These experiments involve 18 full-size DHLW packages emplaced in heavily instrumented vertical boreholes in the salt drift floor. These tests have been in heated operation for over ten months now; the planned test duration is 3 to 7 years. A major purpose of these experiments is to evaluate the in situ materials performance (i.e., degradation or alteration) of various waste package components: metal canisters and overpacks, backfill materials, nonradioactive DHLW glass, and installed instrumentation. These evaluations are being performed under both near-reference and overtest or accelerated-aging repository conditions. This paper describes the current status of the WIPP simulated DHLW experiments and presents initial thermal conductivity results derived from in situ thermocouple (temperature) data. Current in situ backfill thermal conductivities range from 0.28 to 0.43 W/m-°C for bentonite/sand backfills and 1.12 W/m-°C for crushed salt backfill, depending on maximum waste package system temperature(s). Preliminary modeling calculations of thermal conductivity have also been performed using the SINDA and COYOTE codes. The numerically derived values are generally in good agreement with the experimentally measured values, except for the first several days after experiment (heater) turn on.

INTRODUCTION

A total of sixteen full-size, simulated (nonradioactive) DHLW test packages were emplaced in the WIPP facility in 1984[1] for both materials and concept-validation testing. These waste package performance technology experiments are a subset of a much larger WIPP in situ experiment program conducted by Sandia National Laboratories for the US Department of Energy, and are described elsewhere.[2] The overall experimental objectives, techniques, materials, package designs, and instruments used in these tests are also described in more detail elsewhere.[3] The design and goals of these in situ tests are directly based on the research and results of earlier laboratory and field tests conducted by Sandia and other laboratories.[1,3-7]

All of the test DHLW packages (i.e., containers, backfills and waste form) are located in vertical boreholes in the rock salt floor of two test rooms in the WIPP. The test rooms are located at a depth of about 650 m below the surface. Six DHLW packages are located in WIPP Room A1 under near-reference repository thermal conditions. Each of these containers incorporates an internal electric heater with a thermal output of 470 W; these Room A1 packages are part of a three-room-test unit cell with an overall thermal power density of 18 W/m^2. The other ten DHLW test packages are located in WIPP Room B under accelerated-aging, overtest conditions. These conditions include a thermal output of 1500 W/container, a thermal flux into the salt about 3 times greater than in Room A1, the artificial injection of 100 L of brine into 5 of 12 test emplacements (to accelerate interactions), and the introduction of four containers with intentional surface defects. Two of these 10 test packages contain nonradioactive DHLW glass from the Savannah River Laboratory (SRL) and experience thermal loading from external sources. Another two glass-filled containers will be added to the existing test matrix in May 1986. The simulated DHLW tests in Room B have been in heated operation since April 1985; those in Room A1 were turned on in October 1985.[4]

The primary purpose of these 3- to 7 year duration experiments is to evaluate the in situ materials performance of all high-level waste package barriers, including their near-field interactions with the rock salt geochemical "repository" environment. The lack of high-intensity radiation fields from fully radioactive waste form is considered the only simulation in these experiments. Because these experiments are still in their early phases, no material samples have yet been obtained for laboratory evaluations. Previous, early results and technical observations have been reviewed elsewhere.[4]

The need for safe, permanent storage of nuclear waste in various geologic environments requires knowledge for both near- and far-field temperature histories. For a given repository thermal loading, the far-field temperature profiles are determined largely by already known thermal conductivity values of the host rock salt. However, near-field temperature profiles, specifically before a steady state has been reached, are influenced largely by the thermal behavior of the backfill (sometimes referred to as "packing") material surrounding the waste container. Thus, another important objective of these waste package performance tests is the determination of in situ thermal properties of the various emplaced backfill materials. The presentation of current thermal results is a major focus of this paper.

At this time, thermal conductivities of the backfills will be presented as a function of backfill material and temperature. At a later date, following a more thorough analysis of all available data, the

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*This work was performed by Sandia National Laboratories and supported by the US Department of Energy under Contract DE-AC04-76DP00789.

thermal conductivities will also be determined as a function of: time, backfill moisture content, position within the emplacement hole, and backfill compaction density.

EXPERIMENTAL DETAILS

Test Rooms

The simulated DHLW experiments are being conducted in two separate test rooms (mechanically mined tunnels in the rock salt) in the WIPP facility, Rooms A1 and B. Both rooms are 5.5 x 5.5 x 93.3 m in size and are spaced 80 m apart. In Room A1, the waste packages are emplaced into vertical boreholes in the salt floor in a single-row configuration, 1.9 m apart. Each borehole is either 0.76 m or 0.91 m in diameter and 5.5 m deep. In Room B, the waste packages are in boreholes 0.91 m in diameter and 4.9 m deep, in a double-row configuration. The rows are 2.3 m apart. The simulated DHLW packages in both test rooms are collocated with multiple (similarly sized) electric heaters that are being used in separate thermal-structural interactions experiments.[8] As such, the waste packages are part of larger heated-room thermal arrays, as they would be if located in a full-scale operating repository. The initial, ambient air temperature in both test rooms was 27°C. At present, it is about 45°C in Room B and 32°C in Room A1.

DHLW Containers

Three basic designs for DHLW test containers are used in these experiments. The containers in Room B have been fabricated to be essentially identical to the two current, proposed "reference" designs for DHLW: a TiCode-12 disposal container, as proposed and developed at Sandia National Laboratories[5] for testing in WIPP (illustrated in Fig. 1), and a proposed "reference" DHLW container designed by the Office of Nuclear Waste Isolation (ONWI) in 1983[9] and fabricated by Sandia National Laboratories. The TiCode-12 containers are 3.0 m long, 0.61 m in diameter, and have a 0.64-cm-thick wall. They also have a hemispherical dome top 1.91 cm thick, adequately thick to resist expected lithostatic pressures. Four of the TiCode-12 containers have internal 1500 W electric heaters; two other TiCode-12 containers will be filled (to a height of 2.60 m) with nonradioactive DHLW glass provided by Savannah River Laboratory (SRL), and will be added to the Room B test matrix in May 1986. The ONWI-design containers consist of an inner, stainless steel 304L glass-pour canister (3.0 m long, 0.61 m in diameter, and with a 0.95-cm-thick wall), and a thick, outer overpack of cast mild steel A216 grade WCA (3.35 m long, 0.80 m in diameter, and with an overall 8.6-cm-thick wall). Two of the four test stainless steel canisters contain 1500 W electric heaters, the other two have been filled (to a height of 2.31 m) with nonradioactive DHLW glass at SRL.

The test containers in Room A1 are basically a Sandia developmental canister-overpack design for DHLW. They are fabricated from schedule 60 mild steel pipe, nominally 3.0 m tall, 0.61 m in diameter, and with a 2.5-cm-thick wall. They have flat top and bottom heads and a top handling pintle identical to that used on the other "reference" design containers. Half of these test canister-overpacks have a 2.2-mm-thick TiCode-12 overlay wrapped (with no appreciable air gaps) and welded around the mild steel, as well as TiCode-12 pintles, rather than mild steel ones. The Room A1 test containers all have internal 470 W electric heaters. Other details and operational observations on all types of test DHLW containers used are described elsewhere.[3,4]

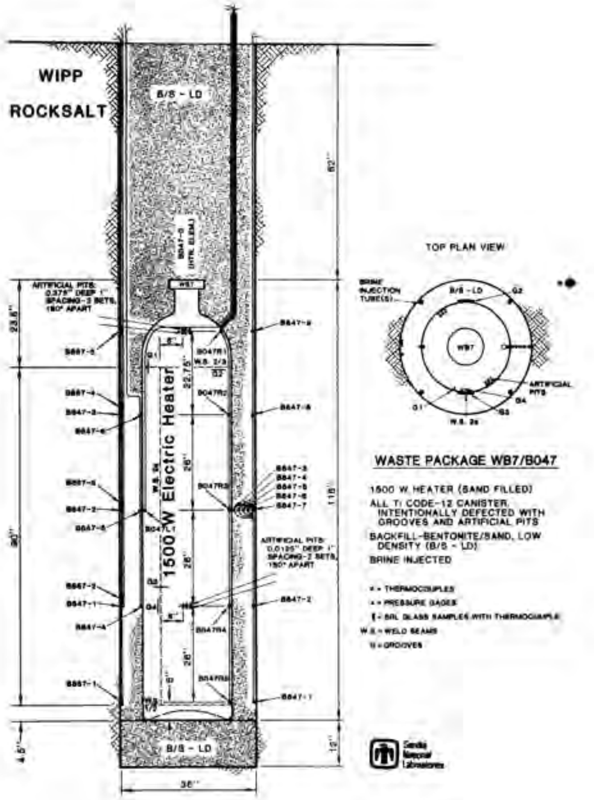


Fig. 1. WIPP Simulated DHLW Test Emplacement

DHLW Glass Waste Form

Two full-size DHLW containers in Room B were filled (and another two will be) with nonradioactive borosilicate glass (TDS 165 black frit) at the TNX pilot-scale vitrification facility at SRL, with equipment prototypic of the future Defense Waste Processing Facility (DWPF). The glass waste form inside these test containers will not be subjected to in situ leaching, but will be used to evaluate the effects of glass filling, transportation, and repository handling, emplacement, and retrieval operations on the physical integrity of the glass. Alterations in glass mechanical properties and fracturing, increases in glass respirable particle concentrations, etc., will be quantified. There are also small cylindrical pellets (13 x 13 mm) of the same DHLW glass located outside the canister and subject to the effects of in situ leaching and interaction. These glass pellets are immersed in the backfill material; their locations are shown in Fig. 1 as B867-1 to 5. These pellets will be periodically retrieved for laboratory analyses. This glass testing and evaluation is a joint WIPP/Sandia National Laboratories and Savannah River Laboratory cooperative effort. The four glass-filled test packages contain no internal electric heaters; instead, they are heated externally by adjacent hot salt--as heated by nearby electric heaters. After about three years of heated emplacement in the WIPP, these four containers will be retrieved for posttest analyses.

Waste Package Backfills

Two separate types of backfill materials have been selected for these tests.[3] Both are granular materials and were poured in place under, around, and above the waste containers, as shown in Fig. 1. The first backfill material is a tailored mixture[6] of 70 wt. % bentonite clay (predominantly sodium and calcium montmorillonite, MX-80) and 30 wt. % silica sand. This backfill material was emplaced primarily adjacent to TiCode-12 DHLW containers. The second, non-tailored backfill material is crushed salt, as mined in the WIPP, then screened so that no particles are greater than 6 mm in size. Crushed salt backfill was used primarily adjacent to mild steel-overpacked, ONWI-design waste containers.

Due to the gradual effect of borehole closure from salt creep, both granular backfills will be compacted in time to higher densities. This compaction will also result in an increase in the effective, in situ thermal conductivities of the backfill materials.[6,7] Changes in emplaced backfill density, moisture content, and geochemical alterations (if any) will be evaluated by means of retrieved material samples. Backfill samples will be retrieved by coring operations (scheduled to start in April 1986), packaged carefully, and then sent to the laboratory for analyses.

In order to increase significantly the rate of interactions (e.g., corrosion, waste form leaching, and backfill geochemical alterations, as compared to that occurring under expected, dry backfill conditions) during the planned course of these experiments, significant quantities of concentrated brine have been injected into 5 of the 12 test emplacements in Room B. 100 L of Brine A,[10] a concentrated Na-Mg-K-Cl-SO_4 brine is being injected at four longitudinal positions on the borehole-backfill interface (as shown in the top plan view on Fig. 1), releasing the brine over the center 50% of the test containers surface. This injected brine is intended to be representative, and an overtest of, inflow expected from the phenomenon of brine migration.[2]

Test Instrumentation

Up to 20 thermocouples have been installed within each simulated DHLW test emplacement and continually monitor the in situ temperatures. They are on the inside or outside surfaces of the containers, on the salt borehole wall, and in horizontal arrays through the backfill materials. These Chromel-Constatan thermocouples are clad in Inconel 600 sheaths, 3.2 mm in diameter, and are accurate to +/-0.5°C. Figure 1 illustrates the location of all instrumentation installed within a simulated DHLW test emplacement containing a TiCode-12 waste container.

Thermal Modeling Calculations

Extensive thermal studies are being conducted to adequately predict in situ conductivity values of the backfill materials.[11] As part of this investigation, thermal models have been assembled making use of the SINDA[12] heat transfer code and the COYOTE[13] heat-conduction code. The SINDA code is a tool for thermal analysis that contains numerous subroutines for handling interrelated complex phenomena; the transient thermal analyses were performed using the CNBACK subroutine, essentially an implicit backward-differencing technique. The COYOTE code is a finite element nonlinear heat transfer computer program where the transient analyses were performed using the Crank-Nicolson method for time integration. A four node, bilinear, quadrilateral element type was used.

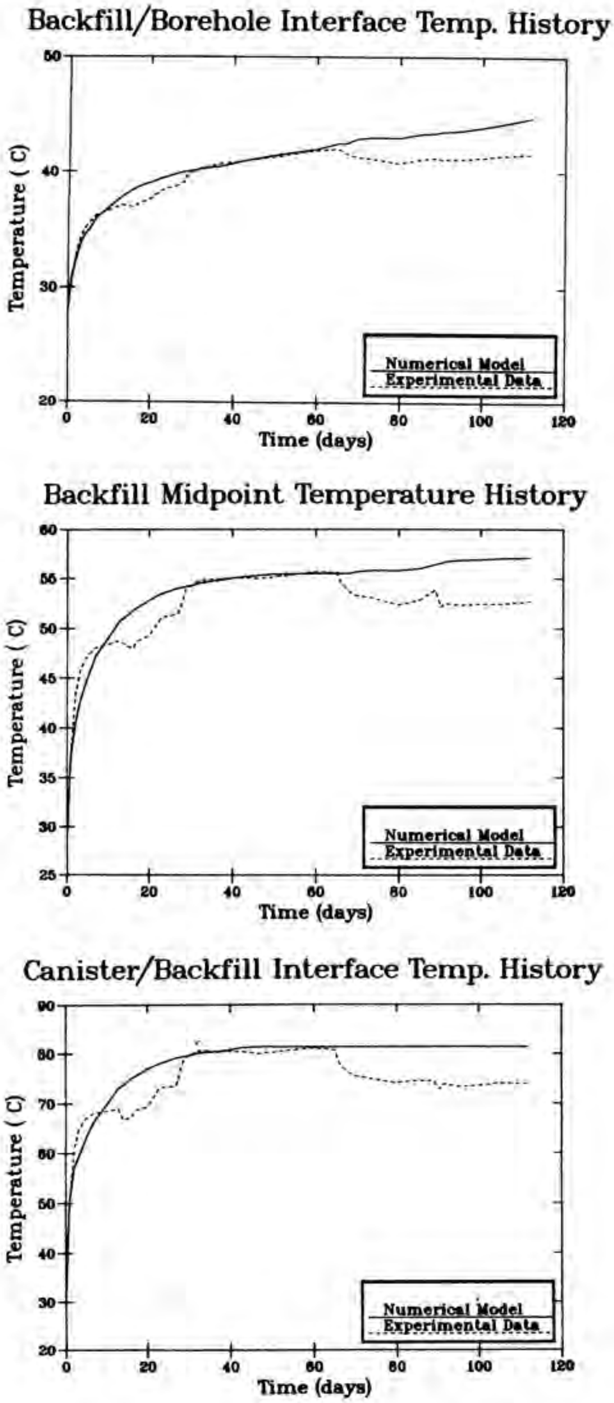
RESULTS AND DISCUSSION

Since no waste package materials samples have yet been retrieved for detailed laboratory analyses, this paper limits discussion to a review of instrumentation data currently obtained and comparisons of such data to the initial thermal modeling calculations.

Thermal conductivity values of the backfill materials were derived by fitting parametric calculations to measured in situ temperature versus time data, as measured with the installed thermocouples. Comparative data plots presented herein show how thermal conductivities under the stated transient conditions and under conventional equilibrium conditions differ, and how these differences affect the predictions for temperature distributions in the near-field.

The measured data and calculated results are summarized in Figs. 2, 3, and 4, and in Table I. The temperature profiles shown in Figs. 2 and 3 correspond to points at the canister-backfill interface, the backfill (annulus) midpoint, and backfill-borehole wall interface, all at the canister mid-height location. The maximum measured temperatures recorded at these same points (as shown in Fig. 1, for example, as thermocouple points B847-3, B847-5, and B847-7, respectively) are also listed in Table I. It should be noted that all measured temperatures are still very slowly increasing with time as this in situ testing continues. In all cases, the measured temperatures are greatest at, or slightly above, the center-height of the waste canisters, decreasing near the canister ends.

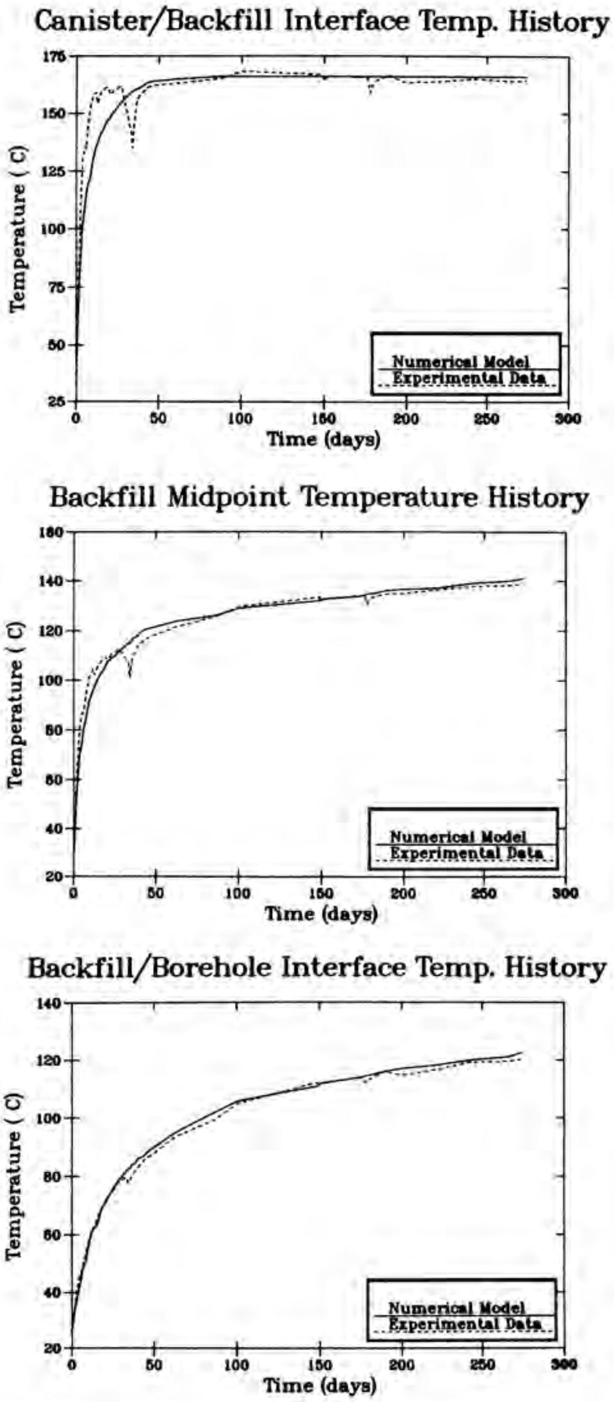
Two waste container systems were analyzed, one containing a 470 W electric heater (in test Room A1), and the other a 1500 W heater (in Room B, as shown in Fig. 1). The results in Fig. 2 correspond to the 470 W system; those in Fig. 3 correspond to the 1500 W system. The backfill material for both emplacements was the granular bentonite/silica sand mixture. Figure 4 shows temperature profiles for basically the same measurement points in a 470 W package system using crushed salt as the backfill (the proposed ONWI-design[9]). The predicted bentonite/sand backfill thermal conductivity at 470 W was found to be 0.28 W/m-°C (averaged over the backfill annulus, at the canister mid-height); the corresponding value obtained for the 1500 W system was 0.43 W/m-°C. The corresponding thermal conductivity value for the crushed salt backfill system at 470 W was found to be 1.12 W/m-°C. The variations in the measured temperature data, most notably shown in Figs. 2 and 4, are due primarily to minor heat power fluctuations and temporary power losses. The profiles found in Figs. 2, 3, and 4 show fairly good measured versus calculational agreement for later times, about 5 days after heater turn on. Appreciable discrepancies are, however, noticeable between the measured versus calculated temperature responses found in the first several days after heater turn on. These discrepancies are believed to be due to the presence of air and moisture initially residing in the backfill near the waste container surface interface. This should effectively result in lower thermal conductivity values, making this interface region act as an insulator. Before this interface region becomes thermally stable, the canister surface temperature rises rapidly. Once the backfill material in the interface region attains a quasi-stable condition, the heat is conducted more efficiently through the region. Further analyses and


Backfill/Borehole Interface Temp. History

Backfill Midpoint Temperature History

Canister/Backfill Interface Temp. History

Fig. 2. Near-Field Temperature Profiles With a Bentonite/Sand Backfill (470 W Emplacement)


Canister/Backfill Interface Temp. History

Backfill Midpoint Temperature History

Backfill/Borehole Interface Temp. History

Fig. 3. Near-Field Temperature Profiles With a Bentonite/Sand Backfill (1500 W Emplacement)

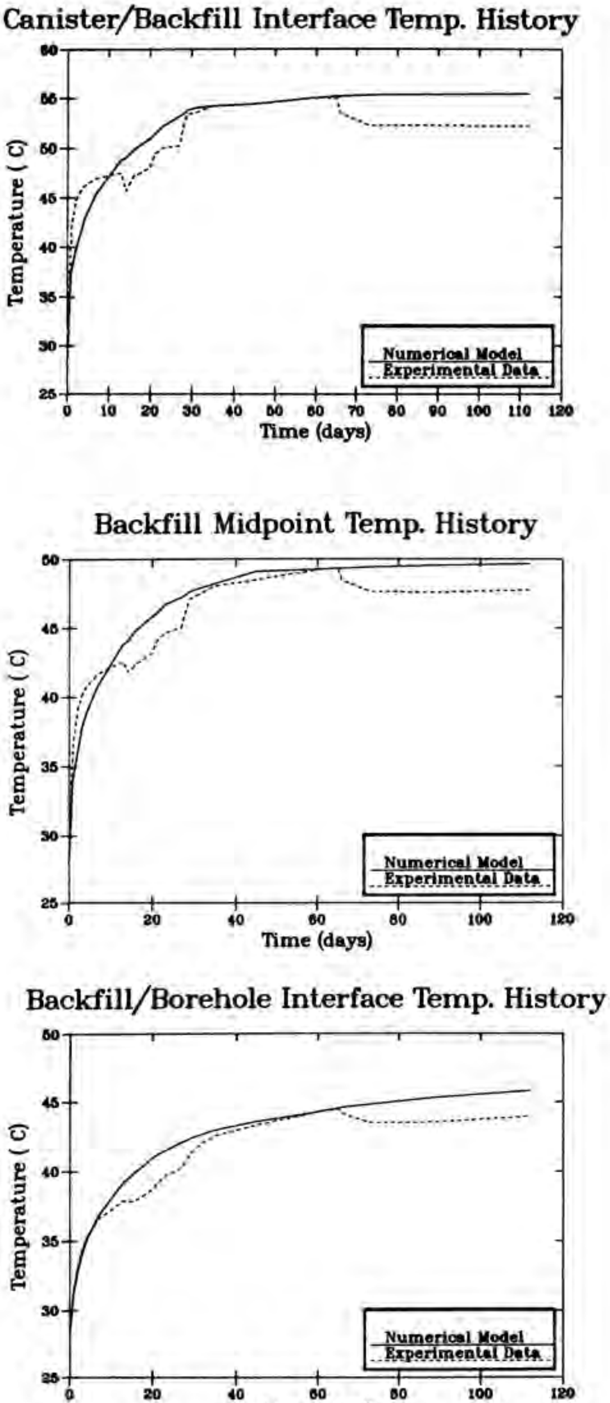


Fig. 4. Near-Field Temperature Profiles With a Bentonite/Sand Backfill (470 W Emplacement)

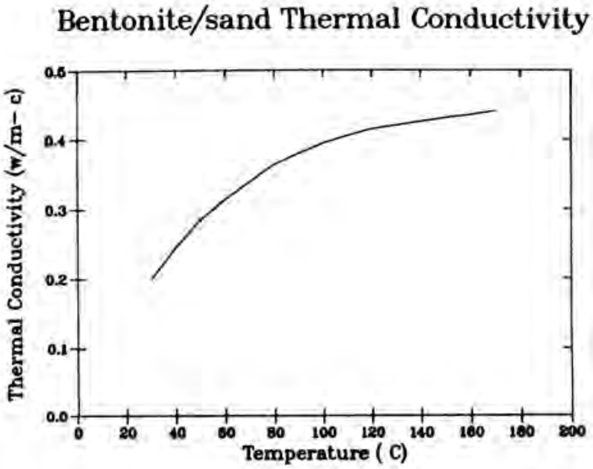


Fig. 5. Thermal Conductivity of Bentonite/Sand as a Function of Temperature (derived from numerical models)

modeling work focusing on the first several days after heater turn on will be performed.

The temperature-dependent, in situ thermal conductivities for the bentonite/sand backfill are summarized in Fig. 5 and Table I. These values range from 0.28 to 0.43 W/m-°C, corresponding to temperatures of 55 and 152°C (328 and 425 K), respectively. Table I also lists conductivity values predicted from mixture theory studies.[14] The lower and upper values were found to be 0.2 and 0.97 W/m-°C, respectively. The backfill material heat capacity change due to temperature increase was not considered in these initial thermal analyses.

Remotely measured data and future in situ material results will be compared with previous laboratory and field test data for analytical modeling verifications, to help provide long-term predictions for high-level waste isolation in salt, and to aid in interpreting the significance of these in situ results. The initial results and testing experience from this series of nonradioactive experiments are presently being used to refine the test plans[15] for fully radioactive, actual DHLW packages to be emplaced and tested in the WIPP beginning in FY90. The results from both the simulated[1,3,4] and future, actual[15] DHLW package tests, and parallel operational tests and demonstrations in the WIPP will help provide the technical basis for adequately resolving issues concerning performance of high-level waste packages in salt. This resolution will be important in assuring the general public and the technical community that the concept of high-level waste disposal in (a future licensed repository in) salt is both valid and safe.

Table I

Backfill Material	Heater* Power (W)	Backfill Maximum Temperatures °C Container Interface	at Backfill Midpoint	Rock Salt Interface	Thermal Conductivity W/m-°C Numerical Modeling	Mixture Theory
70% Bentonite/ 30% Sand	470	81	56$^+$	44$^+$	0.28	0.2 Lower bound 0.97 Upper bound
70% Bentonite 30% Sand	1500	168	139$^+$	119$^+$	0.43	
Crushed Salt	470	56	49$^+$	46$^+$	1.12	

*Power was not constant during test.
+Temperatures are still increasing.

REFERENCES

1. M. A. MOLECKE, "WIPP Waste Package Testing On Simulated DHLW: Emplacement," in Scientific Basis for Nuclear Waste Management VIII, ed., J. Stone and C. Jantzen, North-Holland (1985).

2. R. V. MATALUCCI, C. L. CHRISTENSEN, T. O. HUNTER, M. A. MOLECKE, and D. E. MUNSON, "Waste Isolation Pilot Plant Research and Development Program: In Situ Testing Plan," SAND81-2628, Sandia National Laboratories (March 1982).

3. M. A. MOLECKE, "TEST PLAN: Waste Package Performance Technology Experiments for Simulated DHLW," Sandia National Laboratories (June 1984).

4. M. A. MOLECKE, "WIPP Waste Package Performance Testing on Simulated DHLW: Early Data," SAND85-0559C, presented at the International Topical Meeting on High-Level Nuclear Waste Disposal, Pasco, WA, September 1985, to be published in the conference proceedings.

5. M. A. MOLECKE, J. A. RUPPEN, and R. B. DIEGLE, "Material for High-Level Nuclear Waste Canister/Overpacks in Salt," Nuclear Technology, Vol. 63, 476-506 (December 1983).

6. M. MOSS and M. A. MOLECKE, "Thermal Conductivity of Bentonite/Quartz High-Level Waste Package Backfills," in Scientific Basis for Nuclear Waste Management VI, ed. D. Brookins, North-Holland (1983).

7. M. A. MOLECKE and T. M. TORRES, "The Waste Package Materials Field Test in Southeast New Mexico Salt," in Scientific Basis for Nuclear Waste Management VII, ed. G. McVay, North-Holland (1984).

8. D. E. MUNSON, "TEST PLAN: Overtest for Simulated DHLW Thermal-Structural Interactions," Sandia National Laboratories (June 1983).

9. Westinghouse Electric Corp., "Waste Package Reference Conceptual Designs for a Repository in Salt," WSTD-TME-001 (prepared for the Office of Nuclear Waste Isolation, Columbus, OH) (August 1983).

10. M. A. MOLECKE, "A Comparison of Brines Relevant to Nuclear Waste Experimentation," SAND83-0516, Sandia National Laboratories (May 1983).

11. R. BERAUN and D. A. BENSON, "Measurements of Thermal Diffusion in Fiber-Reinforced Composites," SAND85-1374, Sandia National Laboratories (1986).

12. TRW Systems Group, "Systems Improved Numerical Differencing Analyzer (SINDA)," 14690-HH001-r0-00 (1971).

13. D. K. GARTLING, "COYOTE--A Finite Element Program for Nonlinear Problems," SAND77-1332, Sandia National Laboratories (1978).

14. G. K. BATCHELOR, "Transport Properties of Materials With Random Structure," Ann. Rev. Fluid Mech., Vol. 6 (1974).

15. M. A. MOLECKE and R. V. MATALUCCI, "Preliminary Requirements for the Emplacement and Retrieval of Defense High-Level Waste Tests in the Waste Isolation Pilot Plant," SAND84-1444, Sandia National Labs (October 1984).