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RESULTS FROM SIMULATED REMOTE-HANDLED TRANSURANIC WASTE EXPERIMENTS AT THE WASTE ISOLATION PILOT PLANT (WIPP) **

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ABSTRACT

Multi-year, simulated remote-handled transuranic waste (RH TRU, nonradioactive) experiments are being conducted underground in the Waste Isolation Pilot Plant (WIPP) facility. These experiments involve the near-reference (thermal and geometrical) testing of eight full-size RH TRU test containers emplaced into horizontal, unlined rock salt boreholes. Half of the test emplacements are partially filled with bentonite/silica-sand backfill material. All test containers were electrically heated at about 115 W/each for three years, then raised to about 300 W/each for the remaining time. Each test borehole was instrumented with a selection of remote-reading thermocouples, pressure gages, borehole vertical-closure gages, and vertical and horizontal borehole-diameter closure gages. Each test emplacements was also periodically opened for visual inspections of brine intrusions and any interactions with waste package materials, materials sampling, manual closure measurements, and observations of borehole changes. Effects of heat on borehole closure rates and near-field materials (metals, backfill, rock salt, and intruding brine) interactions were closely monitored as a function of time. This paper summarizes results for the first five years of in situ test operation with supporting instrumentation and laboratory data and interpretations. Some details of RH TRU waste package materials, designs, and assorted underground test observations are also discussed. Based on the results, the tested RH TRU waste packages, materials, and emplacement geometry in unlined salt boreholes appear to be quite adequate for initial WIPP repository-phase operations.

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

DISCLAIMER

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Multi-year, simulated remote-handled transuranic waste (RH TRU, nonradioactive) experiments are being conducted underground in the Waste Isolation Pilot Plant (WIPP) facility. These experiments involve the near-reference (thermal and geometrical) testing of eight full-size RH TRU test containers emplaced into horizontal, unlined rock salt boreholes. Half of the test emplacements are partially filled with bentonite/silica-sand backfill material. All test containers were electrically heated at about 115 W/each for three years, then raised to about 300 W/each for the remaining time. Each test borehole was instrumented with a selection of remote-reading thermocouples, pressure gages, borehole vertical-closure gages, and vertical and horizontal borehole-diameter closure gages. Each test emplacements was also periodically opened for visual inspections of brine intrusions and any interactions with waste package materials, materials sampling, manual closure measurements, and observations of borehole changes. Effects of heat on borehole closure rates and near-field materials (metals, backfill, rock salt, and intruding brine) interactions were closely monitored as a function of time. This paper summarizes results for the first five years of in situ test operation with supporting instrumentation and laboratory data and interpretations. Some details of RH TRU waste package materials, designs, and assorted underground test observations are also discussed. Based on the results, the tested RH TRU waste packages, materials, and emplacement geometry in unlined salt boreholes appear to be quite adequate for initial WIPP repository-phase operations.

INTRODUCTION

We are conducting nonradioactive, simulated remote-handled transuranic waste (RH TRU) experiments underground in the Waste Isolation Pilot Plant (WIPP). These experiments have been in heated operation since September, 1986. These experiments involve the testing of eight full-size RH TRU containers emplaced into horizontal, unlined rock salt boreholes in the ribs, or walls, of WIPP underground Room T. This test room has the same physical dimensions as the actual transuranic waste storage rooms planned for the WIPP facility. Test conditions were designed to be "near-reference" with respect to anticipated thermal outputs of RH TRU containers and their geometrical spacing or layout in WIPP repository rooms.

Simulated RH TRU waste experiments were an important segment of the Sandia National Laboratories-WIPP Waste Package Performance (WPP) program. This program included the direction and performance of all materials-related, and associated technical operations-related, in situ testing on both simulated remote-handled and simulated contact-handled (CH) TRU waste containers and emplacements.[1] The predominant goals of the WIPP WPP testing program were to provide: comprehensive in situ and supporting laboratory data bases for waste package engineered-barrier material selections, testing, and detailed evaluations; fabrication and test experience for waste package designs and design options; and, repository relevant data for the WIPP performance assessment modeling studies. Another major intent of the WPP in situ testing was to provide relevant scientific and technical guidance plus information for supporting regulatory compliance evaluations, and in support of eventual radioactive waste repository operations.

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The specific objectives for this WPP experiment are:

a) To help provide a technical basis for validating the concept of safe RH TRU waste emplacement, retrieval, and disposal in the WIPP. This is as a supplement for, and precursor to, the planned shipment of actual RH TRU wastes to the WIPP.

b) To extend the state-of-the-art of TRU waste package technology, beyond laboratory materials testing, with in situ testing of representative RH TRU waste packages.

c) To evaluate and demonstrate the horizontal emplacement of simulated RH TRU canisters in unlined boreholes in salt, emplaced in a simple, cost-effective manner.

The intent of this paper is to provide an overview, data summary, and survey of technical observations and interpretations from this in situ test. Full background information and objectives for these experiments, plus pretest technical details on the design, setup, and conduct are documented in a separate Test Plan.[2] A full presentation of all data, results, interpretations, and supporting modeling will be documented in a forthcoming, comprehensive data report.

EXPERIMENTAL

WIPP test Room T, as mined, was 3.96 x 10.1 x 45.7 m (13 x 33 x 150 ft), H x W x L in size, and occupies the southern half of the original, 91.4 m- (300 ft-) long, WIPP Site Preliminary Design Validation (SPDV) Room 3. This room is located within a thick layer of competent rock salt, about 95% halite (NaCl), with traces of argillaceous (clay) materials, discontinuous clay partings, and impurities such as anhydrite and polyhalite. The floor of this room is 654 m (2147 ft) below ground level.[2]

Test containers were emplaced into eight unlined, horizontally cored holes in the rock salt ribs of Room T. These boreholes are 0.91 m (36 in.) in diameter and 4.88 m +/- 0.15 m (16.0 ft +/- 0.5 ft) deep. Emplacement hole centers are 1.68 m (5.5 ft) above the floor and 2.44 m (8 ft) apart, with four holes on each side of Room T. The test containers rest 10 cm above the bottom of the salt borehole, on a "borehole container conveyor assembly." Roller wheels on the conveyor assembly facilitate container emplacement, periodic retrievals for examination, and reemplacement.[2] Figure 1 illustrates the test room, boreholes, and emplaced RH TRU containers.

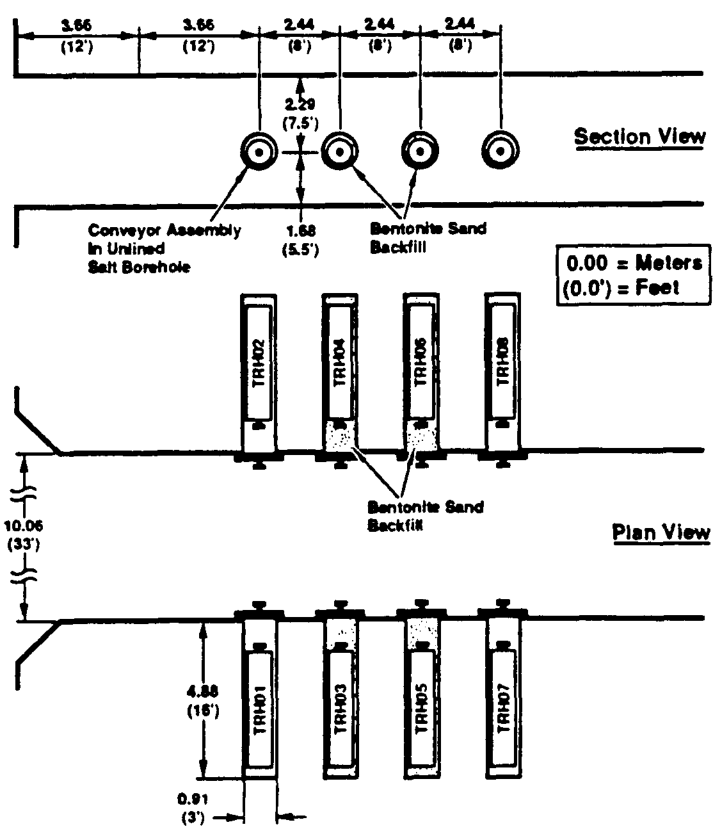

Figure 1. Layout of Simulated RH TRU Waste Experiment in WIPP Room T

Eight WIPP RH TRU waste test containers were fabricated, under contract to Sandia National Laboratories. Rockwell Hanford Operations provided[3] the reference design for these containers, for use by defense waste generator sites in the U.S. Each container is 3.07 m (121 in.)-long, 0.66 m (26 in.) in diameter, and has a maximum internal volume of 0.90 m^3, as designed to incorporate three standard (DOT 17C) contact-handled TRU waste drums, each 210 l (55 gallons) in volume. Each

RH TRU container is fabricated out of ASTM A516-82, grade 70 mild steel, 6.35 mm- (0.25 in.-) thick, and painted with two coats of enamel primer and one top coat.[3] The test containers are illustrated in Figure 2.

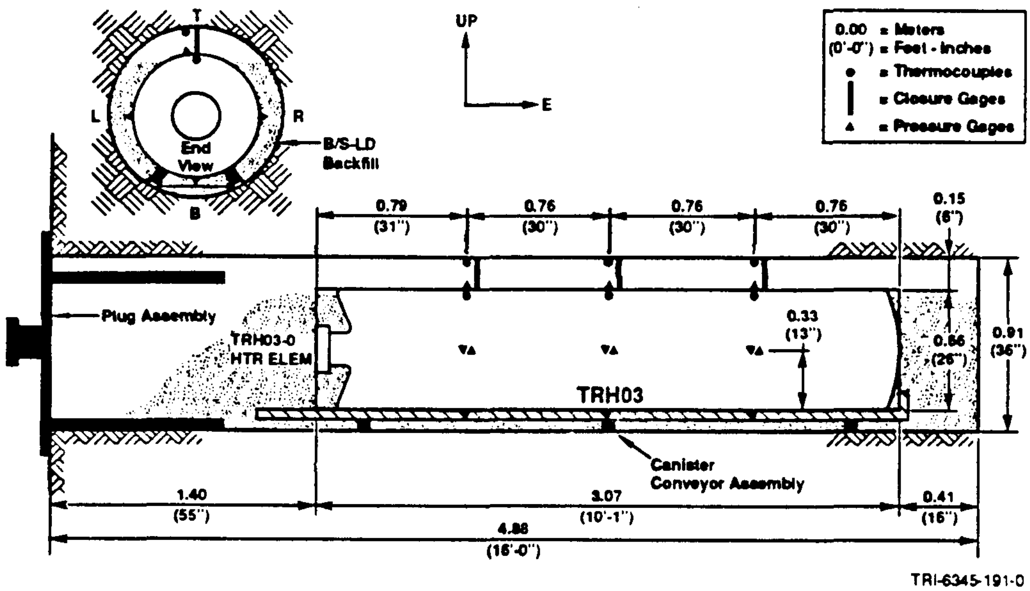

Figure 2. WIPP Simulated RH TRU Waste Test Emplacement TRH03

There is a multiple rod-element electric-resistance heater inside these test containers rather than actual TRU waste drums.[2] At the time of test turn-on, the test containers were electrically heated to about 115 ± 4.5 Watts/each. This power is approximately two to four times the average expected thermal output of actual, radioactive RH TRU wastes to be disposed of in the WIPP. After approximately three years of testing, the electrical heaters were increased to about 299 ± 9.5 W/each for the remainder of the test. This thermal output is the maximum allowable heat output for RH TRU wastes. The higher-power portion of the test must be considered as an overtest, a test accelerant. We have assumed that the near-field environment around actual RH TRU waste packages would be predominantly affected by the heat generated by the wastes. The moderate gamma-radiation field to be anticipated from RH TRU wastes is not expected to have significant chemical and physical impacts on either the near-field and far-field environments or on relevant waste package materials' interactions.

Four of the eight RH TRU test emplacements are partially backfilled with a granular mixture of 70 wt. % bentonite clay and 30 wt. % silica sand; these are illustrated in Figure 1. The other four emplacements have no backfill other than trapped air. The backfill (packing) material, serves the purposes of: a.) sorbing any potential brine intruding into the emplacement hole, b.) sorbing transuranic nuclides potentially leached from the wastes in the long-term,[1] and c.) more efficiently transferring heat to the surrounding host rock salt.[1]

Most of the test emplacements are fully instrumented with remote-reading thermocouples, pressure gages, borehole vertical-closure gages (between the borehole and container-top surface), and vertical and horizontal borehole-diameter closure gages. Relative locations of installed gages are shown in Figure 2. The effects of heat on borehole closure and near-field materials interactions were closely monitored. Each test borehole was opened periodically for visual inspections, manual closure measurements, maintenance, and materials sampling. All gages are connected to a computerized data acquisition system (DAS). Data from each gage have been monitored and recorded every 4 hours since the beginning of the test. A detailed summary of the in situ WIPP DAS and the supporting database management and reduction systems are documented elsewhere.[2]

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RESULTS AND DISCUSSION

Temperatures

The maximum observed heater-thermocouple temperatures (on the container metal surface) were in the range of 36° to 42°C with the heater power output of 115 ± 4.5 W, and in the range of 45° to 58°C with the heater power output of 299 ± 9.5 W. Similarly, the observed near-field temperatures (at the borehole top-air interface) were in the range of 31° to 32°C at the lower heater power output, and in the range of about 35° to 37°C at the higher heater power output. These temperatures should be compared to the observed borehole ambient temperature of 28° to 28.3°C, recorded over a 27 day period prior to heated test turn-on.

In both heater- and near-field temperature cases, there are minor fluctuations in temperature histories with a range of up to 2°C, and a near-sinusoidal periodicity of about one year. These fluctuations were observed over a five-year time period. Minor temperature fluctuations were identified as being due to mine-ambient (air), seasonal temperature fluctuations in the test room, as influenced by underground mine ventilation.

Pressures

Pressures applied to the left and right sides of test containers were measured at three separate distances along the container, at 2.18 m, 2.95 m, and 3.71 m in from the hole rib-face. The maximum observed pressures were always recorded at the furthest distance in, nearer the closed or blind end of the borehole. The minimum pressures were always observed at the midpoint of the container, at 2.95 m in from the rib face.

The monitored pressures increased almost continuously from the time of backfill material emplacement. The highest pressure values observed, e.g., 0.72 and 0.87 MPa (104 to 126 psi) were always followed by subsequent pressure decreases. There were also several occasions of two pressure maxima. It appears that the not-totally-confined, granular bentonite/silica sand backfill is quite capable of transferring stress-loading due to borehole closure, as a function of time, onto the RH container. This capacity is limited, however. In the test boreholes, only partially filled with backfill, the backfill reached a certain amount of consolidation, transferring pressures, before it shifted somewhat, thereby temporarily decreasing its load-bearing capacity. The largest observed rates of pressure increase, up to 0.25 MPa/year (36 psi/year), would yield a maximum pressure of about 1.3 MPa (180 psi) if linearly extrapolated over an undisturbed 5-year test emplacement-retrieval cycle, assuming a fully backfilled waste emplacement hole and no backfill slippage. Visual evaluations of the observed pressure histories in the test boreholes do not reveal any obvious correlation between heater thermal-output, between 115 and 300 watts/heater, and pressure increase.

Borehole Closure Measurements

The maximum measured, vertical-displacement borehole closure after approximately five years of test operation is about 75 mm (3.0 in.). The vertical closure rates were very close to linear with time, with rates ranging from 10.3 to 15.3 mm/year (0.41 to 0.60 in./year), over the 50 to 1826-day test period. There does not appear to be a significant impact on vertical closure rates over the heater-power range used. This is similar to the non-impact seen for pressure increases.

Borehole vertical closure data and rates were also obtained for an about-one-month period prior to heater turn-on. These ambient-temperature closure rates were between 16.9 to 18.6 mm/year (0.69 to 0.73 in./ year). This range of rates was generally about 2 to 5 mm/year faster than the observed ranges over the 50 to 1826-day heated period. Immediately after turn-on of the 115 W heaters, vertical closure rates increased slightly for about 50 days, presumably in response to the thermal output and temperature increase. The initial increases over the pre-turn-on closure rates were in the range of +0.9 to 5.7 mm/year (0.04 to 0.22 in./year) greater. These rates all decreased after about 50 days, down to the reported 50 to 1826 day rates. Both of these observations indicate that minor borehole temperature increases are less important than elapsed time for controlling the observed vertical closure rates.

Observed horizontal-closure vs. distance histories are distinctly different than the vertical-closure histories. Measured horizontal-diameter closure rates seem to indicate a maxima near the borehole mid-point position, between about 2.2 to 3.0 m in from the rib face, and a distinct minima nearer the open end of the boreholes, at 1.23 m in from the rib face. Vertical diameter-closure rates at 1.23 m in from the rib face are in the range of 11.0 to 11.9 mm/year (0.43 to 0.47 in./year). These are approximately a factor of two greater than the horizontal closure rates at the same location, 4.4 to 6.2 mm/year (0.17 to 0.24 in./year). At 3.0 m to 3.7 m in from the rib face, however, the horizontal-diameter and vertical-diameter closure rates appear to be comparable in range, there are no major differences.

Geochemical Sampling and Analyses

All of the test emplacements have been opened for examination from one to five times over the first 36 months of heated operation. A major reason for these examinations was to quantify evidence of brine intrusion. Samples of salt, mineral efflorescences, and clay were taken for geochemical laboratory analyses; backfill samples were analyzed for sorbed brine-residual moisture content. We also made visual evaluations of the effects of brine and slightly elevated temperatures on test container corrosion.

Indications of minor brine intrusions were frequently observed, to varying degrees, in all of the unlined test boreholes. This was primarily evidenced by the presence of occasional, small, blob-shaped efflorescences or stalactite drips on the top-half of the borehole surfaces, and of blob-precipitates, small stalagmites, or drip paths onto small areas of the top or side surfaces of the test containers. The population and size of these evaporated-brine occurrences in most boreholes has increased somewhat with time. These samples ranged in color from clear-white to yellowish-brown. Several efflorescence samples were geochemically analyzed. X-ray diffraction analyses[4] indicated that these samples are primarily halite. Petrographic and scanning electron microscope examinations of similar specimens revealed a variety of minor phases. Likely identifications of these minerals, based on elemental content, are carnallite [$KMg(Cl)_3 6H_2O$], sylvite (KCl), magnesium chloride, clays, and iron sulfate or chloride.

No appreciable liquid brine accumulations were ever observed in the boreholes. Indications of brine intrusion were observed as damp-appearing, slightly darker-colored regions of the backfill. The backfill material sorbs or wicks essentially all brine intruding into the hole from either hole-top drips or side seeps. "Damp-appearing" backfill samples were dried at 110°C and yielded a sorbed-moisture content within the range of 4.5 % to 8.2 wt. %. All of these measured moisture values are somewhat greater than the nominal moisture value of about 3.9 wt. % for unused, initial bentonite/sand backfill. Moisture content within the emplacements decreased somewhat as a function of time, as the available brine dried out in the slightly warm borehole.

Corrosion Observations

All of the RH TRU test containers have been qualitatively evaluated for signs of surface corrosion. There were either small blobs of salt crystals remaining on the cans, or, at the worst, slightly yellowish-colored stains and salt crystals on the paint. Corrosion on the painted areas of all containers is considered insignificant, for at least the first 36 months of heated testing, in the relatively mild corrosive test borehole-environment. The corrosion-prevention capability of the reference[3] enamel paint used on the containers is adequate, but the mechanical abrasion resistance (paint hardness, durability) of the paint was less than ideal. During initial canister handling and emplacement activities at the WIPP, several test containers had areas of paint scraped off or appreciably scratched. These areas were spot painted or touched-up, with more of the original paint, prior to test emplacement. Such spot painting might prove difficult if the containers had included actual, radioactive RH TRU wastes. The unpainted, mild steel pintles of all containers exhibited superficial rusting, which has become more "flaky" as a function of time, but is still not considered significant. The RH TRU container bodies appear to have more than adequate physical integrity to remain unbreached by corrosion for more than the anticipated, initial five-years of a WIPP pilot-phase retrieval period.

CONCLUSIONS

This report summarizes laboratory and in situ data, in situ observations, and preliminary conclusions on the WIPP Simulated RH TRU Waste Experiment. A full presentation of all results over the first five-years of test operation will be documented in a separate, comprehensive data report. A comparison of in situ temperature and borehole closure measurements to a 3-dimensional, thermal-structural computer modeling analysis has also been conducted and will be presented in the data report. In situ results support the use of tailored, i.e., bentonite-containing backfill materials in WIPP TRU waste storage, particularly for the short-term sorption of brine and to hinder potential, long-term transuranic radionuclide migration[1] or dispersal. Current results on the interactions of heat, waste package materials, limited amounts of intruding brine, and the quantified rates of salt borehole-closure and resultant pressures indicate that similar, but radioactive (actual) RH TRU containers should be quite adequate for repository-phase isolation in unlined, horizontal salt boreholes. There should be no restrictions on WIPP RH TRU waste acceptance due to observed waste package performance. This conclusion is particularly applicable for the anticipated, initial five-years of a WIPP pilot-phase retrieval period.

Results from these simulated RH TRU tests will be combined with ongoing WIPP mechanistic modeling and performance assessments, and planned actual TRU waste tests on brine-leaching, source-term evaluations (in the laboratory) and waste degradation, gas-generation tests (in the WIPP). The sum total of experimental and modeling analyses will help provide the technical basis to predict the long-term performance of radioactive waste packages in WIPP salt.

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