CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Atlas Facility Site Visit—Natural Convection Test (20.01402.661)

DATE/PLACE: May 14, 2002
Las Vegas, Nevada

AUTHOR: R. Fedors

DISTRIBUTION:

CNWRA

W. Patrick
CNWRA Directors
CNWRA Element Managers
R. Green
A. Ghosh
D. Gute
G. Ofoegbu
B. Dasgupta
S. Hsiung
S. Painter
L. Browning

NRC-NMSS

J. Linehan
D. DeMarco
E. Whitt
B. Meehan
J. Greeves
J. Schlueter
W. Reamer
K. Stablein
T. Essig
D. Brooks
J. Pohle
B. Leslie
D. Esh
D. Galvin
M. Nataraja
B. Jagannath

SwRI Contracts

T. Nagy (Contracts)
P. Maldonado

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Atlas Facility Site Visit—Natural Convection Test (20.01402.661)

DATE/PLACE: May 14, 2002
Las Vegas, Nevada

AUTHOR: R. Fedors

PERSONS PRESENT:

Randy Fedors of the Center for Nuclear Waste Regulatory Analyses (CNWRA), Robert Latta [U.S. Nuclear Regulatory Commission (NRC)], and Robert Johnson (NRC) visited the Atlas Facility in North Las Vegas, Nevada, for a tour of the natural convection laboratory tests. The tour was led by Cliff Howard (Principal Investigator for the test) and Hemi Kalia (onsite, Los Alamos National Laboratory). The tour took place on May 14, 2002.

BACKGROUND AND PURPOSE OF TRIP:

Two U.S. Department of Energy (DOE) and NRC technical agreements in the Thermal Effects on Flow Key Technical Issue, TEF2.04 and TEF2.05, request an assessment of the cold trap process and its affect on performance of the repository. The cold trap process refers to moisture movement in the open drift caused by small to large scale thermal gradients. Water will evaporate in hotter areas and condense in cooler areas. Condensation directly on waste packages could occur, though it is more likely that condensation will occur on other parts of the drift infrastructure and then drip on the drip shield or waste package. Though condensation is expected to occur preferentially on cooler surfaces, the type of surface is also a factor.

To learn about the DOE work with respect to TEF2.04 and TEF2.05, a tour of the natural convection laboratory test was arranged. Laboratory testing of natural convection is an important step in understanding and modeling the cold trap process in the drifts.

DOE measurements of temperature, airflow patterns, and flux rates made in the Atlas Facility laboratory test will be used as input or calibration for computational fluid dynamics simulations using the commercially available FLUENT code. Thermally-driven natural convection, however, needs to be combined with evaporation and condensation to address the cold trap process. The natural convection test does not include phase changes (evaporation and condensation), nor does the associated computational fluid dynamics modeling of the natural convection laboratory test. Staff at the Atlas Facility are not charged with estimation of the effect caused by phase changes and moisture movement, which are integral to the cold trap process.

SUMMARY OF PERTINENT POINTS AND ACTIVITIES:

The test plan (Bechtel SAIC Company, LLC, 2002), which was obtained prior to the Atlas Facility visit, listed a series of eight tests, four with a drip shield and four without. The tests were performed in 25 percent scale and 44 percent scale laboratory models. Uniform and nonuniform power distributions were another perturbation to the tests; both waste package spacing and input power to each scaled canister were to be used to distribute the heat load. A preliminary, non-quality-assured-data presentation prepared on April 24, 2002, was handed out during the tour. The presentation contained cross-sectional and longitudinal plots of nearly all of the tests listed in the test plan (Bechtel SAIC Company, LLC, 2002). A copy of the presentation can be obtained from the onsite NRC representative or from Randy Fedors. Two tests remain to be completed in the series of tests listed in the test plan. Observations and discussion topics during the tour are briefly described in the following paragraphs.

The rationale for test design was described in the test plan (Bechtel SAIC Company, LLC, 2002). Scaling principles based on geometry and the heat transfer coefficient were applied. Geometric scaling factors were applied to the (i) diameter of the drift, (ii) diameter and length of the waste packages, (iii) height of the invert, (iv) location of the waste package relative to the invert, and (v) geometry of the drip shield. Scaling of heat transfer, however, was simplified by ignoring radiative heat transfer. The Nusselt number, which was used to scale the thermal aspects of the laboratory test, is a ratio of the heat transfer mechanism and the total heat transfer. Inertial, buoyant, and viscous forces are incorporated into the Nusselt number. Scaling of heat transfer coefficient leads to the reduced input power scaled by the square of the geometric factor (0.0625 for the 25 percent scale model and 0.194 for the 44 percent model). The thermal output predicted at 300 years after emplacement was used to determine scaled temperatures for the laboratory models. The Rayleigh number, which is the ratio of gravity and thermal diffusivity, varies by a factor of 5 between the tests; it will vary further for the actual size drift.

Intuitively, scaling of natural convection in a heated drift should be nonlinear and complex. The complexity of the scaling is most readily understood by considering the switching of prominence of different heat transfer processes at different scales. Radiation, convection, and conduction may all be important heat transfer mechanisms in these laboratory tests with their relative importance being a function of the test scale and temperature differences between the canister and the drift wall. If the components of the three heat transfer processes can be separated, it will be done by modeling, not by measurements made in the laboratory based on information obtained during this tour. By performing tests at two different, yet, relatively large scales, scaling issues become less prominent for simulations of repository drifts at Yucca Mountain.

The 25-percent scale model has a length of 11 m and a diameter of 1.6 m. The 44-percent scale model has a length of 17.6 m and a diameter of 2.6 m. Six different waste package designs were mixed in each test, depending on whether the test considered a uniform or distributed heat load. For tests with a drip shield in place, one continuous shield (no gaps) was used. Invert material consisted of crushed tuff with an approximate diameter of 2–3 cm. The sides and one end of the cement cylinder were covered by 2-inch thick insulation, which was in turn covered by a reflective foil. The other end of the cement cylinder was covered by a highly reflective metal surface and 12-in thick insulation, which was intended to mimic a no-flux boundary condition consistent with an internal position in the drift.

Two basic assumptions of the laboratory tests were that initial conditions and heating history do not affect final flow patterns. All important measurements were made once steady state was attained, though transient information was also recorded. The tests were jump-started by overpowering the canisters, then dropping the input power after one day down to a level expected to produce the desired temperatures at the surface of the canisters.

The measurement objectives were (i) radial and axial temperature distributions, (ii) detailed radial air velocity (above the drip shield when present), (iii) qualitative flow visualization, (iv) heat flux distribution in the cement pipe and surrounding insulation, (v) relative humidity distribution throughout the test section, (vi) power input to each waste package, and (vii) ambient conditions in the test bay. In addition to radiative, convective, and conductive heat transfer through the air space in the scaled drift, conductive heat transfer from the canister through the metal infrastructure to the invert was considered in the test design. Numerous thermocouples and a lesser number of relative humidity probes were installed through ports on the sides of the cement cylinders. Thermocouples were placed in the air space, on surfaces, and in objects inside the cylinder. Thermocouples and anemometers were also manually moved between measurement stations along transects in the air space. Heat flux by conduction through the cement pipe, by conduction through the outside insulation, and by conduction and convection to the room air, will be estimated using the temperature data. Room temperature, barometric pressure, and relative humidity in the test bay were also measured. However, wind currents are strong in the test bay and diurnal variations would be expected to be prominent. Barometric pressure fluctuations outside the test cylinder may enhance airflow leakage between the test and the surrounding environment similar to what occurred in the Drift-scale Heater Test at Yucca Mountain. Perturbations of the flow field may occur, particularly when measurements of temperature and air speed along transects were obtained.

Flow visualization was performed in the 25-percent scale model by releasing small (<2-mm diameter) helium soap bubbles into a side port and viewing the circulation pattern using a camera with an attached light source. Qualitative visual observations were recorded in their scientific notebooks. Video capture of the soap bubbles will allow for later image processing to better track the flow pathways.

Monitored ambient environmental conditions can be linked along with the electrical grid power fluctuations to changes in conditions inside the tests. Power fluctuation on the electrical grid can lead to significant fluctuations of temperatures inside the scaled models. Input wattage and output temperatures from the canisters are monitored—one reading per hour. Temperatures inside the cylinder are out of phase with environmental conditions outside the test due to a delay in the propagation of signals across the insulation and cement cylinder.

Cross-sectional plots of temperature were displayed for each of the completed tests. Maximum temperatures reached were 32 °C and maximum temperature differences within the drifts were about 8 °C. The addition of a drip shield leads to higher temperatures near and at the canister and invert. Slightly lower ceiling temperatures in tests with the drip shield may reflect the decreased convection caused by the sealed drip shield. Nondirectional measurements of air flow rates were generally near the signal limit of the anemometers (0.05 m/s). Computational fluid dynamics simulations using the FLUENT code compared favorably with measured values of air flow rate; simulated values were within 20 percent when measured values were above 0.05 m/s. Only two-dimensional simulations, however, have been completed.

Three-dimensional simulations using FLUENT are planned and will be critical for understanding the clearly three-dimensional flow field. Axial and cross-sectional plots of temperatures suggest prominent communication between zones of the test drift.

Simulated temperature values using a two-dimensional grid appear to be consistent with trends of the measured data. The simulations were performed using higher values of outside temperature (a boundary condition in the simulation) and are presumably being redone using actual, measured conditions. There is a broad zone of upward flow above the canisters and a narrow zone downward along the walls. Staff has some concern that the placement of temperature sensors in the test cylinder do not appear to be useful for confirming the realism of the computational fluid dynamics simulations. Temperature variations would be expected to reflect the flow fields. Four thermocouples are fixed in identical locations for each cross section; the positions do not cover a range of flow activity (low rates and high rates) and leave a wide latitude for FLUENT simulations in matching the test data. The high flux zones in the simulated flow fields are tightly focused along the edge of the cylinder with an apparently small boundary layer. No measurements were made in the zones of high air flux (fixed positions or along the transects). Delineation of flow pathways using gas bubble injected into the test cylinder may provide confirmation of the FLUENT simulation results. Though the gas bubble injections may suffer the same problem as measurements made along the transect using the open port, the flow field may be perturbed by the measurement process.

There are no additional tests scheduled for the natural convection work. Perhaps after data interrogation and modeling are complete, DOE may consider additional testing. On a related matter, the ventilation test was adjacent to the natural convection test. Because no further testing is planned, DOE is currently evaluating the costs for disassembling the laboratory ventilation test model.

IMPRESSIONS/CONCLUSIONS

The testing series is nearly complete. Data from the entire test series will be in the DOE Technical Data Management System by July 15, 2002. The combination of the test plan and scientific notebook were stated as being sufficient to understand the data submitted to the Technical Data Management System; no reports are expected in the near future.

The natural convection test does not include the phase change (evaporation and condensation), nor does the associated computational fluid dynamics modeling. Staff at the Atlas Facility are not charged with estimation of the phase change and moisture movement, which are integral to the cold trap process. Based on discussion during the tour, it could be inferred that DOE intends to factor in the phase change aspect to the cold trap process in other numerical models, such as the Multiscale Thermohydrololgic Model. Other than incidental data that may have been collected in the Passive Test in the Enhanced Characterization of Repository Block when thermal gradients were present, no known field or laboratory data will be available to support the DOE cold trap model.

REFERENCES:

Bechtel SAIC Company, LLC. "Atlas Natural Convection Test Plan." SITP–02–EBS–002. Rev. 00. Las Vegas, Nevada: Bechtel SAIC Company, LLC. January 2002.

PROBLEMS ENCOUNTERED:

None. DOE and its contractors were extremely helpful in all aspects.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

The data should be requested when it becomes available in the DOE Technical Data Management System on July 15, 2002, for evaluation and possible confirmatory modeling.

Additional contacts with DOE staff should be made for the purpose of understanding how the cold trap process will be evaluated by DOE. The natural convection test does not include all important processes for a cold trap; specifically, evaporation and condensation are not considered.

SIGNATURES:

Randall W. Fedors
Randall Fedors
Research Engineer

5/21/02
Date

CONCURRENCE:

Asad Chowdhury
Manager, Mining, Geotechnical, and Facility Engineering

5-21-2002
Date

Budhi Sagar
Budhi Sagar
Technical Director

5-23-202
Date