CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: 13th Thermal Test Workshop (20.01402.661)

DATE/PLACE: November 1–2, 2001; Albuquerque, New Mexico

AUTHOR: R. Fedors

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PERSONS PRESENT:

Photocopies of the sign-up sheets for the two days of the Thermal Test Workshop listing persons present, their affiliations, and contact information are attached as Appendix A. Randy Fedors from the Center for Nuclear Waste Regulatory Analyses (CNWRA) attended as an observer.

BACKGROUND AND PURPOSES OF TRIP:

The purposes of this trip were to attend the 13th Thermal Test Workshop, observe the Department of Energy (DOE) approach to testing and modeling of coupled thermal-hydrologic processes, and gather information to assist in issue resolution. The thermal test workshops are the primary forum for dissemination of information and integration of activities among the research staff of DOE and its contractors regarding the thermal testing program at Yucca Mountain, Nevada. The meeting agenda is included as Appendix B.

MEETING SUMMARY:

The 13th Thermal Test Workshop was held at the Airport Marriott Courtyard Hotel in Albuquerque, New Mexico, November 1–2, 2001.

At the onset of the meeting, the CNWRA observer was reminded that technical comments, ideas, and opinions expressed at this workshop are not intended to be considered formal stances of DOE. Comments attributed to DOE or contractor staff during any thermal test workshop should not be referenced or quoted in documents released to the public. An understanding was reached with DOE for future workshops, though DOE staff now also realize that contrasting scientific opinions reflect uncertainty that should be incorporated into their analyses.

Besides updates from each researcher that serve the purpose of fully integrating the work among all researchers, a prime objective of the meeting was to discuss the cool down schedule. The heaters are scheduled to be turned off on January 14, 2002. A slate of sampling, geophysical measurements, and camera traverses was presented for discussion. A summary of the discussions from each day of the meeting is presented in the following two sections.

November 1, 2001

After a brief introduction, Steve Sobolik turned the projector over to Yvonne Tsang who reviewed the Drift Scale Test objectives, configuration, and instrumentation. Tsang reiterated that the objective of the Drift Scale Test is thermohydrologic model validation, not process modeling to create abstractions for the performance assessment of the proposed repository. The important data from the Drift Scale Test for supporting the thermohydrologic model are the temperature and the tracking of the two-phase zone. Besides the continuously monitored temperature; the data used to track thermohydrologic processes in the thermal tests are air permeabilities as measured in the boreholes equipped with packers, and geophysical measurements of electrical resistivity tomography, ground penetrating radar, and neutron probe logging collected on a periodic interval of a few months. All of these methods are used to track mobilization and redistribution of pore water in the fractures and matrix of the Topopah Spring welded tuff.

The question of interpretation of changes in measured air permeability arose. Tsang attributed most of the changes in air permeability during the test to changes in fracture saturation. This conclusion is based on borehole data that generally exhibit lower air permeability readings as the reflux front approaches, then recover as the front passes by. Interpretation of changes in air permeabilities measured quarterly in the packer-equipped hydrology boreholes, however, is not straightforward. Evidence that thermomechanical effects may also contribute to changes in air permeability is illustrated in some boreholes where decreases or increases in air permeability are not consistent with changes expected by fluctuation in fracture saturation. Air permeability changes could also be caused by increases or decreases in secondary mineralization in the fractures, but this is assumed by Tsang to be of minor importance.

Tsang also pointed out the difficulties in identifying refluxing of water and possible penetration into the drying front. Increased temperature oscillations are thought to indicate the passage of the refluxing zone. She suggested that one reason for possible confusion was that temperature and relative humidity probes are located in the top of packed-off borehole sections, whereas water collection apparatus is at the bottom. The situation is reversed for boreholes below the drift. Interpretations of water chemistries depend on the identification of the hydrological processes and conditions relevant to those water samples.

John Case presented his analysis of the power and temperature data from the Drift Scale Test, which is nearing the completion of the fourth and final year of heating. A series of five power reductions to the heaters has occurred, with the first reduction occurring 2.2 years into the expected 4 years of heating. The purpose of the power reductions is to maintain drift wall temperatures near 200°C. The hottest areas of the drift wall occur about midway down the heated drift near the wing heaters at the drift springline, where temperatures are about 209°C, while the ends of the heated drift near the bulkhead (~192°C) and at the concrete-lined far end (~198°C) are cooler. The asymmetry of temperatures along the axis of the drift is caused by heat losses from the bulkhead. There is also an asymmetry of temperatures around the drift walls with the springline temperatures being highest and floor temperatures being the lowest. The springline temperatures are the highest because of the wing heaters. This asymmetry is not present in the wallrock based on contours of temperature data from the boreholes. It was suggested that the low thermal conductance of the inverts affected the low temperatures on the drift floor, but that the thermal conductance of the wallrock readily compensates so that, in cross-section, the temperature distribution and dryout zone is symmetrical above and below the drift.

Mary DeLoach updated the group on progress towards resolving the source of high fluoride values from a few of the water samples. These samples also have a low pH (3.1 to 3.5). There appears to be an association between packers from a specific supplier and the high fluoride water samples. The technical specifications from the supplier of vitron packers clearly state that the packers are not designed for application in steam environments. Thus, breakdown of the packers continues to be the working hypothesis for the unusual chemistry of a few of the samples. In support of this hypothesis, Nicolas Spycher noted that evaporation could not lead to the high fluoride based on measured levels of other ions, nor could CO_2 level alone cause a reduction of pH to around 3.

DeLoach also reported on differences in major cation chemistry of water collected from boreholes above and below the heated drift. Previously, based on fewer samples, it was believed that the major cation chemistry was different above and below the drift. With more water samples now analyzed, average major cation levels from above and below the heated drift are approximately the same, though, samples from above the drift exhibit more variation. DeLoach also commented on whether the water collected in the boreholes was derived from condensate or liquid water that had seeped into the borehole. The collection apparatus samples both liquid water and moist air, which is condensed in the sample lines or collection bottle. Interpretation of the differences in chemistry between samples led to the hypothesis that some water samples were condensed from moist air. Temperature data and the location of the refluxing zone are used to indirectly confirm whether moist air is sampled and later condensed.

Brian Marshall questioned the validity of the current conceptual model using two points. First, he asked whether heterogeneity plays the prominent role in different volumes collected from different boreholes (e.g., water is still being collected from borehole 59 but borehole 60 is now dry). Subgrid heterogeneity (e.g., channelized or rivulet flow) could be important but is not included in the conceptualization. If heterogeneity is not the cause, the question is whether the water comes from seepage or condensation. Condensation may be important if one considers that seepage requires flux rates on the order of tens of thousands of mm/yr to overcome capillary barriers at the borehole boundary. The question would then be whether model predictions for water movement and chemistry should be accepted if the conceptual model for mass movement into boreholes is incorrect. The second point made by Marshall dealt with the use of an ambient, homogeneous water chemistry to interpret water samples from the Drift Scale Test. A plot of major cations was presented that illustrated the strong heterogeneity of pore water chemistry from the Enhanced Characterization of Repository Block drift. It was not clear if the figure represented pore water chemistries from both the middle nonlithophysal and the lower lithophysal units, or just the latter.

Mark Conrad presented ^{13}C, ^{14}C, δD, δO, and CO_2 data from water and gas samples. Three different distributions of CO_2 over time were observed in different boreholes. One distribution reflected an increase in CO_2 with increasing temperature followed by a sharp drop as boiling occurs. A second temporal distribution showed a steadily increasing CO_2 level. A third distribution exhibited an increase followed by a plateau. The last distribution was said to reflect a limit in the source of CO_2. Supporting the control of CO_2 levels by the dissolution of secondary calcite minerals in some of borehole locations, ^{13}C data indicated that the primary source of CO_2 was calcite dissolution rather than from gas. Similarly, ^{14}C levels from some borehole intervals (e.g., interval 78-3) exhibited sharp drops to around 10 percent of modern levels. For reference, the ^{14}C levels of the calcite in fractures would be less than about 5 percent of modern levels, while the bicarbonate in pore water would be in the range of 40-60% of modern levels.

From a study of drift air on both sides of the bulkhead of the Drift Scale Test, Conrad concluded that ^{14}C at 98 percent of modern levels in the well-mixed air of the heated drift indicated an effective transfer across the bulkhead to the ventilated Exploratory Study Facility air. Present-day atmospheric ^{14}C is about 110 percent of modern levels.

Schön Levy reported on the sidewall samples collected from borehole 54 above the heated drift. Previously, the locations of these sidewall samples were in the region of condensation and drainage. This location is now in the dryout zone. While it is unfortunate that no existing fractures were captured in the sidewall coring, it is conclusive that all the secondary minerals formed because of the heater test. General conclusions were re-iterated from previous workshops that: (i) there are indications (textures) that support water interacting with the wallrock (tuff) rather than with previous secondary mineralization, (ii) zones of more variability in pre-test mineralization are correlated with zones of more variability of during-test mineralogy, (iii) thick silica deposits capped by one last thin deposit likely reflect precipitation during refluxing followed by one last episode of deposition due to evaporation, (iv) gypsum was not found in pre-test samples but is common in during-test samples, and (v) the need to remove dust covering the cores by air blasting likely leads to loss of some secondary mineralization. The zeolites stellerite and heulandite were found, but it is not clear if they formed because of the heater test. New, unknown minerals were found by Levy, who is trying to obtain samples for x-ray analysis. One new mineral was a magnesium-rich silicate, which would make this the first mineral identified with magnesium. Other new minerals were found in a cluster of at least three unknown minerals that contained a prominent sulfur peak but a small calcite peak (thus none of them could be gypsum).

E. Sonnenthal had a brief summary of the coupled thermo-hydrologic-chemical model. While silica is deposited above and below the heater drift in simulations, the amounts differ markedly. Just as for gypsum, the silica deposition is prominent above the drift and minor below the drift. With regard to geochemical models, no discussion was included on results comparing base case mineralogy (calcite, silica polymorphs, and gypsum) to the extended mineralogy case (includes minerals such as mordenite, stellerite, various clays, zeolites, and other aluminosilicates). Sonnenthal did note that many packers are failing, which was a concern given the limited amount of data for the simulations to match. Sonnenthal is currently considering the effect of ventilation, particularly on the CO_2 cap created above the drift during the heating phase.

Steve Sobolik said that thermomechanical data were used for primarily two purposes. One deals with structural stability of the design (e.g. what are the thermomechanical rock properties of the rock unit and will thermal processes reduce rock integrity). The other concerns effects on flow of long-term thermomechanical changes in permeability. Sobolik continues to analyze perturbations in the displacement data measured by the Multi-Point Borehole Extensometer systems to known events occurring in the Drift Scale Test. Problems persist in the degree of noise in the data. An extreme example was the September 19, 2001 event when all transducers became erratic, possibly due to a single power surge. Sobolik's primary comment during the discussion was on the possible connection between a measured 2-mm displacement in one of the boreholes and the spalling of rock fragments from the ceiling of the heater drift last spring. The displacement occurred over a 30-day period and was recorded by one of the Multi-Point Borehole Extensometers. Since the timing of the spalling was not constrained to less than a month's period by visual observations through the bulkhead door, Sobolik is still unsure of the connection between the Multi-Point Borehole Extensometer data and the spalling. A closer watch during the initial cool-down period may help explain noisy displacement data and any connections to spalling.

An improved camera system, primarily an improvement in the lighting, appears to be providing sufficient quality imagery to identify spalling locations. The camera is mounted at the small door in the bulkhead on a track that runs the length of the heater drift. A plan was discussed to detect changes from images taken by the camera using specific locations and camera angles. The camera is expected to be used extensively during the initial period of cool-down for spalling, and seepage, or dripping. The possibility of dusting the entire drift to aid in detection of dripping was also discussed.

S. Blair presented results from two different models using the UDEC code. The models differ in the boundary conditions applied at the lateral sides. The base case has stress boundary conditions on all sides of the model domain. The other case, referred to as the mixed boundary condition case, has stress boundary conditions on the top and bottom, but has zero displacement conditions on the lateral sides. Blair presented numerous figures illustrating the marked differences in results between the two models. Results from the base case model were generally symmetric, while those from the mixed boundary condition case were asymmetric about the drift. A comparison of the two model results with measured displacement data was inconclusive; some borehole data matched the base case model, other borehole data matched the mixed boundary condition model, and the remaining borehole data were not reasonably matched by either model. Based on matching Multi-Point Borehole Extensometer data, both models would be considered acceptable. Tiltmeter boreholes, as used in the Enhanced Characterization of the Repository Block, might be helpful in supplying field data that could distinguish the two models. Blair noted that a comparison of displacement estimates with changes in air permeability data is needed.

November 2, 2001

R. Wagner and R. Jones led discussions on the evolution of plans for the thermal tests and the scheduled data collection during the initial period of cool-down period after the heaters are shut off on January 14, 2001. A stepped lowering of the heat source, rather than a complete shutdown is believed to represent a worse-case scenario. Since the initial period of cool-down is expected to be the most active period of changing conditions, a slate of sampling, geophysical measurements, and visual observations has been planned for a four-week period following the heater shutdown. The same sampling, monitoring, and observations currently employed will be implemented on a shorter cycle than was done during the heating stage. Plans for the following period are expected to evolve based on results from the initial cool-down period.

M. Eliassi reported on the activities associated with estimation of heat and mass loss from the bulkhead of the Drift Scale Test. Smoke tests and hanging ribbons were used to observe the flow patterns near the bulkhead. The ventilation system imposed a circulation cell within the access drift that led to a complex flow system near the bulkhead. Eliassi also described the circulation cell that formed at the bulkhead where hot air flowed out the top and cool air flowed in through the lower portion of the bulkhead to the heater drift. The magnitude of the flux varied with atmospheric conditions imposed by the ventilation system. Diurnal variations were expressed by cyclical periods of condensation and no condensation on the outside wall of the bulkhead. To measure the heat and mass loss from the bulkhead, arrays of temperature and relative humidity probes were placed in the area immediately outside the bulkhead of the Drift Scale Test. Different configurations were used because of difficulties in obtaining meaningful data. Fans were used to keep condensation from occurring on the bulkhead. In one attempt, a tarp was placed about 18 ft from the bulkhead along with fans to help create a uniform zone of temperature and relative humidity. The ventilation system was modified to reduce the effect of the associated large air flow rates on the conditions near the bulkhead. Conditions with and without ventilation were analyzed. When meaningful data were collected, the temperature was observed to gradually respond to ventilation and fans in an expected fashion. The relative humidity data, however, exhibited complex behavior including sharp changes when ventilation conditions changed and gradual daily increases and decreases. No spatial gradient was observed in the data, and variations in relative humidity were not always consistent with temperature data. A simple modeling exercise was used to estimate heat and mass losses based on the temperature and relative humidity data. The drift volume outside the bulkhead was discretized based on sensor locations. Since the results of the model calculations were highly dependent on the assumed affected volume and no data were presented that reflected the conditions of the access drift, no results on predicted heat loss are included here. Furthermore, it can be assumed that the mass loss is currently on the decreasing end of an asymptotic curve. Hence, an uncertain estimate of the mass loss rate will be even more uncertain when extrapolated back to the times when the mass loss would have been much greater. The follow-up discussion by DOE researchers and contractors centered on the possibility of including the uncertainty in the modeling, rather than attempting to refine the heat and mass loss measurements. This means that DOE will again use the thermo-hydrologic model, which is calibrated to data that include heat and mass loss from the bulkhead, to estimate heat and mass loss from the bulkhead.

S. Mukhopadhyay presented an analysis of the heat and mass balance based on the thermo-hydrologic numerical model of the heater drift environment. The bulkhead and access drift are included as boundary conditions in the model. Two simulations were run using different boundary conditions for the bulkhead; one with the access drift modeled as an infinite source boundary and one with the access drift near the bulkhead treated as a no flux boundary. Fracture saturations are as large as 40 percent in the closed bulkhead simulation, but only average 10 percent in the open bulkhead simulation. A heat and water balance led to estimates of 13 percent heat loss.

W. Lin reviewed the conclusions from the Large Block Test at Fran Ridge. The final report was completed but is awaiting release by DOE. Lin summarized the conclusions as follows: (i) condensate refluxed and penetrated the dryout zone; (ii) it was not possible to distinguish discrete fracture flow and condensate; (iii) heating did not alter the rock matrix; (iv) microbes survived heating up to 240°C and migrated to the collection borehole over a period of nine months; (v) either the thermal expansion coefficient or the number of fractures in the thermo-hydrologic model could be modified to match the measured temperature and water content data.

G. Bodvarsson commented via telephone on possible Yucca Mountain Project activities that could affect thermal testing. The Cross Drift Thermal Test was reaffirmed as being delayed to FY2003. Bodvarsson led a discussion that concluded that the possibility of Low Temperature Operating Modes being considered for the License Application should not affect or cause changes to existing thermal testing plans or numerical modeling of thermo-hydrological-chemical or thermo-mechanical processes. An informal discussion took place on the implications of the possibility of accelerating a License Application from FY2006 to FY2004 by switching the repository emplacement drift design from lower lithophysal unit based to middle nonlithophysal unit based. The rationale was that there were more thermo-hydrologic and thermo-mechanical data, and hence less uncertainty, to support a design where most of the drifts were in the middle nonlithophysal unit.

Documents

The Thermal Test Progress Report documenting activities prior to the 12th Thermal Test Workshop has been completed and will be given to the NRC onsite representative soon. D. Barr noted that the informal Thermal Test Progress Reports will be replaced by an Analysis and Model Report (AMR) that might be updated annually. The purposes of this Analysis and Model Report would be to centralize all the thermal testing data in one location, document anomalous data or behavior as is already being done, and provide a basis for thermal model validation. Whereas the current Thermal Test Progress Report series cannot be referenced and has non-quality assurance status, the Analysis and Model Report could be referenced and would have quality assured status.

The Near-Field Environment Process Model Report will not be updated in the future. Instead, this information will be included in the Unsaturated Zone Process Model Report.

The final report on the Large Block Test at Fran Ridge is complete. A CDROM with the report will be given to the NRC onsite representative soon. It has not yet been determined whether this will be released only as Lawrence Livermore National Laboratory report #132246, or if it will also be released as a Yucca Mountain Project report (TDR-NBS-HS-000012).

The Multiscale Thermohydrologic Model (ANL-EBS-MD-000049) Rev 00 ICN 03 that was stated as being due July 2001 in Technical Agreement TEF2.09 and which will be delayed until November 2001[1], should be changed to version Rev 00 ICN 02.

IMPRESSIONS/CONCLUSIONS

Three important topics for thermal testing are: (i) model validation, (ii) heat and mass loss from the bulkhead of the Drift Scale Test, and (iii) identification and incorporation of uncertainty into total system performance assessment.

On the subject of model validation, it is not always obvious when the DOE is using test data to calibrate or validate a model. For example, the DST data were used to calibrate THC model parameters for kinetic mineral reactions, but DST data are also said to "validate" the THC model. It would be helpful to reviewers and other interested parties for the DOE to clearly identify and separate test data used for model calibration from data used for model validation.

Heat and mass loss for the Drift Scale Test was extensively discussed during the meeting. DOE is evaluating whether to: (i) incorporate the uncertainty brought about by the losses, or (ii) expend further effort to obtain field data to characterize the losses. It may be prudent to follow the former path since peak losses likely occurred early in the test and have been asymptotically decreasing. Hence, a highly uncertain estimate of a small fraction of the losses may not be worthwhile.

The Cross Drift Thermal Test was not discussed at the workshop except to note that has now been delayed to FY2003. This test is important to the Thermal Effects on Flow Key Technical Issue because it represents a possible replacement for the Drift Scale Test. The Cross Drift

[1] Letter from S. Brocum to W. Reamer, Transmittal of Reports Addressing Key Technical Issues (KTI), October 12, 2001; ADAMS ascension number ML012910392.

Thermal Test could be designed to avoid the uncertainty of heat and mass loss from the bulkhead, as occurred at the Drift Scale Test, thus biasing conclusions on shedding locations or on focused flow of refluxed water penetrating the dryout zone.

The last topic, incorporation of uncertainty into performance assessment, was not extensively discussed during the 13th Thermal Test Workshop. In the trip report for the June 2001 Thermal Test Workshop, D. Hughson noted that DOE discussed an effort to quantify uncertainties in performance assessment.[2] After a review of the uncertainty presented in Analysis Model Reports and Process Model Reports, it was recommended that a systematic procedure needed to be developed for identification and quantification of uncertainties, bases need to be provided for probabilistic parameter distributions, and there should be an AMR describing specifically the development of conceptual models. Another purpose of this effort was to identify major unquantified uncertainties, determine if these uncertainties were bounded or addressed by conservative assumptions, and assess whether these would be replaced by quantified uncertainties. The process to document and incorporate the models and parameters was not discussed at the 13th Thermal Test Workshop. The uncertainty in specific tasks or modeling efforts was discussed, however. For example, the uncertainty of assuming *a priori* that the thermohydrologic model parameters were correct so that heat and mass loss could be estimated by simulation was discussed. The equivalent continuum model and different variations of the dual-permeability model, and active-fracture versus constant interaction coefficient, were presented as representing model uncertainty. Also, the uncertainty associated with interpretations of geophysical data and with instrumentation measurement errors was also discussed.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

None

[2] D. Hughson, Twelfth Thermal Test Workshop, Summerlin, Nevada, June 7–8, 2001: Trip Report. Memorandum (July 9, 2001) to U.S. Nuclear Regulatory Commission. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses. 2001.

SIGNATURES:

Randall W. Fedors — 11/28/01

Randall Fedors
Research Engineer

Date

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Mining, Geotechnical, and Facility Engineering

Date

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Budhi Sagar
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Appendix A

13th Thermal Test Workshop
Albuquerque, New Mexico
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13th Thermal Test Workshop
Albuquerque, New Mexico
Attendee List on 11/1/2001

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Appendix B

Thermal Test Workshop Agenda
Airport Marriott Courtyard Hotel, Albuquerque, NM
November 1 and 2, 2001

The primary purpose of this thermal test workshop will be to discuss current results from the Drift Scale Test and related issues. The workshop will be held in Salons A and B of the Airport Marriott Courtyard Hotel at 1920 Yale Blvd in Albuquerque. The bridge number is 702-295-6111. The agenda is provided below [Note: Nonstandard hours on November 1st reflect travel conflicts the previous day - Halloween].

Thursday - November 1, 2001

2:00 PM Welcome and Introductions by Steve Sobolik

2:10 PM TH Model Validation: Integrated Assessment of Thermal and Hydrological Measurements and Agreement with Results from Numerical Analyses. Discussion led by Yvonne Tsang

4:30 PM Break

4:45 PM THC Model Validation: Integrated Assessment of Chemical Measurements and Agreement with Results from Numerical Analyses. Discussion led by Eric Sonnenthal

6:00 PM THM Model Validation: Integrated Assessment of Mechanical Measurements and Agreement with Results from Numerical Analyses. Discussion led by Steve Blair

7:15 PM Open Discussion / Social Hour

Friday, November 2, 2001

8:00 AM DST Heating/Cooling Schedule led by Ralph Wagner

8:30 AM Update on Field Activities led by Bob Jones

9:00 AM Measurement of Heat and Mass Loss Through the DST Bulkhead led by Medhi Eliassi

9:30 AM DECOVALEX - DST Activities led by Robin Datta / Steve Sobolik

10:00 AM Break

10:15 AM Large Block Test Final Report led by Wunan Lin

10:45 AM YMP Activities Affecting Thermal Testing led by Bo Bodvarsson

11:00 AM Open Discussion

NOON Adjourn