CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Tenth Thermal Workshop
(20.01402.661 and 20.01402.561)

DATE/PLACE: May 11, 2000
Livermore, California

AUTHORS: D. Hughson and L. Browning

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PERSONS PRESENT:

CNWRA staff in attendance at the Tenth Thermal Workshop were D. Hughson and L. Browning. Mysore Nataraja attended from the NRC.

BACKGROUND AND PURPOSE OF TRIP:

The purpose of the trip was to attend the Tenth Thermal Workshop held at Lawrence Livermore National Laboratory and to gather information relevant to issue resolution. These thermal workshops are the primary forum for dissemination of information and integration of activities regarding the DOE thermal testing program at Yucca Mountain, Nevada. The meeting itinerary is included as an attachment.

ISSUE RESOLUTION:

Subissue 1 of the Thermal Effects on Flow Key Technical Issue is substantially resolved. The remaining open acceptance criterion of this subissue regards mass and energy losses through the thermal bulkhead separating the heated drift of the Drift Scale Test (DST) from the connecting drift and the Exploratory Studies Facility (ESF) tunnel system. CNWRA staff have raised concerns that the unknown losses through the bulkhead could complicate interpretation of the DST, perhaps resulting in nonconservative assessments of repository performance. Specifically, loss of water vapor and latent heat through the leaky bulkhead and into the tunnel ventilation system could result in reduced condensation forming in the reflux zone, diminishing the rate of return flow towards the heated drift, and reducing the potential for observing refluxing into the heated drift. This has direct implications for repository performance since Revision 3 of the Repository Safety Strategy proposes using the rate of refluxing for the seepage abstraction model during the heating phase of the repository. Misinterpreting DST results by neglecting the effect of losses through the bulkhead could lead to small values for reflux rates being obtained from process models and, consequently, potentially overly optimistic assessments of repository performance. When this item came up on the agenda at the Tenth Thermal Workshop, the discussion became quite animated. Two proposals are pending with the DOE to measure losses through the bulkhead at the DST, one from the University of Nevada and the other from Lawrence Berkeley National Laboratory (LBNL). Managers from the M&O maintained that the thermal-hydrologic (TH) models were sufficient to account for losses through the bulkhead based on matching measured temperatures. Scientists from LBNL on the other hand, namely S. Ballard and B. Freifeld, argued that such an approach was circular reasoning and that water lost as vapor through the bulkhead could be as much as one third of the water removed from the thermally induced dryout zone around the heated drift. The discussion was tabled without any consensus other than that an internal meeting of the DOE thermal testing team was needed to determine how to proceed.

Information was gathered from L. DeLoach, M. Conrad, and E. Sonnenthal before and during the meeting to further resolution of ENFE subissue 2. However, substantial questions were raised as a result of these interactions, and ENFE subissue 2 remains open. As a follow-up to the meeting, L. Browning has contacted the relevant Workshop speakers and asked them to clarify various aspects of their work. These questions were generally related to uncertainties about the physical source(s) for the sampled waters and gases, the collection and analysis techniques applied to these samples, data reliability, and the relationship between specific data analyses and expected repository performance.

SUMMARY OF PERTINENT POINTS:

S. Blair (LLNL) was host for this, the tenth, in the ongoing series of thermal workshops. S. Ballard reported on data related to power to the canister and wing heaters. As of May 11, the DST has been heating for more than 900 days. About 100 days earlier, power was reduced to all heaters by 5 percent and reduced again another 5 percent about two weeks before the workshop. Air temperatures in the heated drift range from about 180–200 °C with the central region higher than the ends. Significant variability is seen in temperatures on the heated side of the thermal bulkhead, ranging from around ambient up to about 150 °C. This variability is an indication of the complex transfer of heat through the bulkhead by barometrically influenced convection. The 5 percent power reductions were made in order to attain the targeted 200 °C drift wall temperature. However, there is significant variability in drift wall temperatures, the hottest regions being near the wing heaters, raising the question as to where the targeted 200 °C temperature should be measured. It was determined that the targeted 200 °C temperature shall be at gauge #196 located in the drift crown about midway along the heated drift. The hottest temperature recorded in the rock mass of 247 °C occurred in borehole 164. This Resistivity Temperature Detector (RTD) gauge is located in close proximity to a wing heater. Temperatures in the longitudinal horizontal boreholes, 79 and 80, show the most "character", probably due to focused liquid and vapor flow in fractures although some gauges in these two boreholes are suspected of being faulty.

S. Sobolik reported on mechanical measurements in the Multipoint Borehole Extensiometer (MPBX) gauges and comparisons between these measurements and pretest predictions based on models of elastic rock behavior. The general tendency is for the models of elastic behavior to underpredict the measurements, indicating that the elastic models are missing something in terms of the magnitude of rock displacements for thermal loading conditions. Plans are to redo the elastic analyses using a larger domain and *in situ* stress boundary conditions and also to use a compliant joint model. S. Sobolik also presented data indicating that the rate of thermal expansion of concrete is strongly dependent on temperature and shows hysterisis.

Y. Tsang presented results of the active and passive monitoring in the hydrology boreholes. Passive monitoring is merely the monitoring of pressure which closely follows the barometric signal. Active monitoring consists of permeability measurements by means of air-injection which are compared to pretest baseline permeabilities. Interestingly boreholes with permeability ratios above 1, that is an increase in permeability above the pre-test baseline, are boreholes 74 interval 4 and 57 interval 3 which are highest above the heated drift and farthest away from the dry out zone. Permeabilities should decrease if condensate is collecting in the fractures and should increase only in the dry out zone due to removal of ambient fracture saturation. Y. Tsang speculated that the increases in permeabilities in the temperature region of 50–60 °C above the dry out zone result from thermal-mechanical opening of microfractures. Several property sets were mentioned during this presentation. Y. Tsang showed results using a property set she identified as TTFY99, indicating that this property set corresponded to the DKM conceptual model with a matrix-fracture area interaction factor of 1. Other results were obtained using the Active Fracture Model (AFM) property set identified only as DS. Significant differences in fracture saturations could be seen in the results presented. Using the TTFY99 property set, ambient fracture saturations were in the range of 10–15 percent while using the DS property set they were 1 percent or less. Also results using the DS property set failed to capture some heat pipe signatures.

A. Rameriz presented the latest results from Electrical Resistivity Tomography (ERT). Using rock temperatures and two different inverse models, estimates of bulk saturation are obtained from measurements of electrical resistivity. These results show vertical asymmetry with more drying above than below the heaters. As of January 10, 2000, two drying fingers could be seen clearly developing above the heated drift. Increases in saturation can be distinguished below the heated drift but are not obvious above.

Ground Penetrating Radar (GPR) tomography results of saturation presented by J. Peterson compare reasonable well to those obtained by ERT. However, the GPR data show an increase in saturation in a zone approximately 1 m thick above the wing heaters as well as approximately 5 m below the heated drift. J. Peterson also presented acoustic emissions data. Two fairly large acoustic events occurred between December 1999, and February 2000, above the heated drift near the concrete liner at the far end. Almost all of the significant events since the onset of heating have occurred within about 12 m above the crown of the heated drift.

Saturations from neutron logging data were presented by R. Carlson. Neutron logging boreholes are two fans of boreholes collared in the Access/Observation Drift (AOD), one at 26.5 m from the bulkhead consisting of boreholes 64-68 (neutron boreholes N06-N10), another at 6.5 m from the bulkhead consisting of boreholes 47-51 (neutron boreholes N01-N05), and the two horizontal boreholes parallel to the heated drift (boreholes 79 and 80). Borehole 66 (N08), located approximately 2 m above the wing heaters, still shows no drying. Borehole 51 (N05) below the heaters began to show some drying starting after 747 days of heating. Borehole 80 running parallel to the heated drift about 3.5 m above the wing heaters, that had produced some water, has completely dried out. The two horizontal boreholes clearly show evidence of preferential flow along fractures at about 23 m and about 45 m from the collar.

L. DeLoach presented results of aqueous chemistry from the hydrology boreholes 60, zones 2 and 3, 61 zone 3, 186 zone 3, and 59 zones 2, 3, and 4 that have collected water. Of interest were discussions regarding the previous sample collected from borehole 59 interval 4 that had 1200 mg/L Cl. Originally this sample was thought to have been contaminated by grout. However, aggressive leaching of a grout sample demonstrated that grout contamination was not the source of the high Cl concentration in 59-4. Now the thought is that this concentration may have resulted from evaporation of matrix pore water. However a question was raised that did not receive a satisfactory answer. If this water was derived by evaporation of matrix pore water, how did the water get out of the matrix and into the borehole in the liquid phase? Water compositions were interpreted as having evolved due to some combination of evaporation or H2O/rock interactions. Questions remaining, however, include the need for more information about the sampling and measurement techniques used, the reliability of the data itself, and the role of these analyses in process-level and PA calculations.

M. Conrad presented results of carbon isotope analyses of gas and water samples collected from the hydrology boreholes. The highest CO_2 concentration of 96162 ppm at 24 months of heating occurred in borehole 59. This sample also had the highest δ^{13} of - 1.7. For comparison, gas inside the heated drift had a CO_2 concentration of 431 ppm with a δ^{13} of -9.9.

B. Marshall independently came to the same conclusion as L. DeLoach that, based on Sr isotope data, the high Cl concentration sample from borehole 59-4 could have resulted from evaporation and concentration of matrix pore water. However, the U concentration in water from 59-4 is lower than that of matrix pore water, suggesting that some process other than evaporation and concentration of matrix pore water is needed to account for the anomalous 59-4 water sample. Typical ratios of Sr^{87}/Sr^{86} in water collected from the hydrology boreholes are in the range of 0.7105 to 0.7125. Lower ratios of around 0.7085 collected from borehole 80 are consistent with grout contamination.

R. Wagner spoke briefly about the thermal testing AMR. This report will include an evaluation of the DS property set for the AFM conceptual model and sensitivity analyses for the other property sets. Simulations using the AFM property set show vertical symmetry in matrix saturations around the dry out zone while simulations using the DKM property set show vertical asymmetry in matrix saturations. R. Wagner mentioned a DOE administrative procedure requiring statements about model validation in the AMRs. Apparently the thermal test modelers decide upon a definition of model validation and then demonstrate whether or not their models satisfy that definition. It was decided that the definition for TH model validation would be if temperature measurements were matched to within something like 15 percent error and, thus, all of the models were determined to be valid. Since all the property sets use dry thermal conductivities from 1.56 to 1.67 W/m/K and wet thermal conductivities from 2.0 to 2.33 W/m/K for the tsw34 hydrostratigraphic unit, models using all the various property sets match the temperature data reasonable well and no one property set was determined to be "the best".

E. Sonnenthal is using TOUGHREACT version 2.0 with the AFM conceptual model for simulation and analyses of the DST. New features of this model are temperature dependent CO_2 diffusion and nonlinear rate laws for mineral precipitation and dissolution. The current model has 19 minerals including fluorite, clinoptilolite, hematite, and tridymite. Mineral abundances and reactive surface areas have been modified based on the 3D mineralogical model. Modeled CO_2 concentrations were shown to match the data fairly well. Good agreement between measured pH in borehole 60-3 and model results was obtained using a subset of minerals with no aluminosilicates. Including the aluminosilicates shifted modeled pH higher than measured values perhaps, as E. Sonnenthal speculated, due to incorrect reaction rates or thermodynamic properties. Model results show calcite precipitating above the heated drift and some calcite dissolution below the heated drift after about 20 months of heating. However, changes in fracture porosity are very small. The current DS property set has a fracture porosity of about 1 percent and the change in this fracture porosity predicted by the model is in hundredths to thousandths of a percent. One potential problem with the use of the active fracture model, mentioned by E. Sonnenthal, is that the active fracture model may underestimate precipitation because of its sensitivity to surface areas.

N. Spycher presented a brief discussion on how low pH values measured in samples collected from the hydrology boreholes could be explained by condensation in a closed system with CO_2.

S. Blair presented results of a model of mechanical rock deformation focusing exclusively on the major mapped fractures. Selection of fractures used in this model was based on large aperture size, secondary mineralization, and subjective judgment. The domain was approximately 70 × 40 × 40 m modeled with *in situ* stress boundary conditions. The model predicted opening of fractures above the AOD and heated drift and some shear on a few major fractures, particularly the one seen from neutron logging data in boreholes 79 and 80 approximately 10 m from the bulkhead.

R. Wagner presided over a short but animated discussion of mass and energy losses through the thermal bulkhead. Currently, the DOE is considering two independent proposals to measure mass and energy losses through the bulkhead. However, R. Wagner and D. Barr indicated a strong preference for attempting to bound those losses using a modeling approach. Modeling performed by K. Lee showed as much as 35 kW convective heat loss through the bulkhead and strong sensitivity to the barometric pumping effect. During the discussion it was suggested that, over the course of the DST, water lost through the bulkhead could amount to as much as one third of the water removed from the dry out zone and about 20–30 percent of the available heat.

Y. Tsang and K. Lee presented preliminary modeling results for design of the Cross-Drift Thermal Test (CDTT). Y. Tsang looked at a heater spacing of 6.5 m with a thermal loading of 290 W/m and a 3.25 m spacing with thermal loads of 290 and 200 W/m. For the higher thermal load and larger spacing, the boiling isotherm had extended into the rock 20 cm by 6 months and 30 cm by 9 months of heating. Using the 290 W/m thermal load and smaller heater spacing the boiling isotherm had extended 70 cm into the rock by 6 months and 110cm into the rock by 9 months of heating. The current test design calls for 6 months of heating prior to injection of water and termination of heating at 9 months. According to these models, a flux rate of 2000 mm/yr will be required to achieve breakthrough with the 200 W/m thermal load and 3500 mm/yr for the 290 W/m thermal load. No definition was given as to the meaning of breakthrough nor was any mention made of the effect of excluding water from small diameter boreholes by the capillary barrier mechanism. This was the first time any staff from NRC/CNWRA had seen or heard of these modeling results even though we were invited by DOE to participate in a teleconference a few weeks ago to give feedback on the CDTT design.

CONCLUSIONS:

Dramatic differences in modeled fracture saturations occur using the various conceptual models and property sets and yet, according the DOE procedure as implemented by the thermal test modelers, all of these models are equally valid.

The Workshop seemed useful as a forum for DOE workers to discuss their data and compare results. There was little discussion, however, about how the interpretation of the various types of data, collected in different places at different times and at different scales, were being integrated and used for model validation or PA calculations.

PROBLEMS ENCOUNTERED:

D. Hughson's flight into Oakland was canceled and United lost her luggage. She was rescheduled on a flight seven hours later and would have missed the meeting, but she refused to get off the airplane at LAX and thus made it to the meeting on time.

L. Browning's attempts to obtain information relevant to issue resolution from Workshop speakers both prior to and following the meeting were met with limited success. Based on comments made at the Workshop, email messages written by L. Browning to the Workshop speakers may have been forwarded to DOE management. A recent letter from L. DeLoach to L. Browning indicates that DOE workers are "being told to get approval for all requests (regarding issue resolution) from outside the lab," suggesting that direct lines of written communication between DOE and CNWRA scientists on technical issues related to issue resolution may be either unfeasible or significantly delayed.

PENDING ACTIONS:

During the discussion regarding losses through the thermal bulkhead it was decided to convene an internal meeting of the thermal test team to decide on how to proceed with accounting for these losses. D. Barr was requested by CNWRA staff to notify NRC/CNWRA staff when this meeting was held and decisions made.

RECOMMENDATIONS:

Several aspects of the DST need to be closely followed and linked to issue resolution. Among these are the consequences of losses through the thermal bulkhead, the source of the high concentrations in water from 59-4, implications of the results of the various hydrological property sets, the meaning of "model validation", the implications of increased permeabilities above the heated drift beyond the zone of condensation, and the design of the CDTT.

Transference of technical information between DOE and CNWRA workers is needed to expedite issue resolution, but direct written correspondence between these groups now appears to be subject to DOE programmatic review. L. Browning is concerned that the inability to transfer technical information directly between DOE and CNWRA staff may result in significant delays and impede efforts to maintain a constructive scientist to scientist rapport. One possible solution is that the NRC site representative act as an intermediary between DOE and CNWRA workers in cases where written transfer of information is required.

SIGNATURES:

Debra Hughson
D. Hughson
Performance Assessment

May 24 2000
Date

Lauren Browning
L. Browning
Geohydrology and Geochemistry

May 24 2000
Date

CONCURRENCE:

Asad Chowdhury
Manager, Mining, Geotechnical, and Facility Engineering

5/26/2000
Date

Budhi Sagar
Technical Director

5/25/2000
Date

ATTACHMENT

Tenth Thermal Test Workshop
Lawrence Livermore National Laboratory
Livermore, California
May 11, 2000

There will be a thermal test workshop in Livermore, California on Thursday, May 11, to discuss the results to date from the thermal tests. The workshop will be held in the Conference Room in Building 219 on East Avenue at LLNL. We will follow the agenda given below :

Thursday, May 11, 2000

8:30AM	Welcome and introductions	Steve Blair

DRIFT SCALE TEST

8:35 AM	Drift Scale Test thermal measurements (temperature and heater power)	Sandy Ballard
9:00AM	Mechanical measurements	Steve Sobolik
9:25 AM	Hydrological active testing and passive monitoring	Yvonne Tsang
9:50 AM	ERT measurements in the DST	Abe Ramirez
10:15 AM	Break	
10:30 AM	GPR measurements &acoustic emissions in the DST	John Peterson
10:55 AM	Neutron logging measurements	Richard Carlson
11:20 PM	Analyses of water samples from the DST	Laura DeLoach
11:45PM	Lunch	
1:00 PM	Gas and water sample analyses	Mark Conrad
1:25 PM	Sr/U Isotopic analyses of DST water samples	Brian Marshall
1:45 PM	Thermal tests thermal-hydrological AMR	Ralph Wagner
2:10 PM	Thermal tests T-H-C AMR	Eric Sonnenthal
2:35 PM	T-H-M Simulation of the Drift Scale Test	Stephen Blair
2:50 PM	Break	
3:05 PM	Future thermal test reports and AMRs	Ralph Wagner
3:15 PM	DST Heater Power Adjustment(s)	Robin Datta
3:25 PM	Heat & Mass Flow Through the Bulkhead	Ralph Wagner
3:35 PM	Cross Drift Thermal Test Planning	Robin Datta
3:45 PM	Pretest Simulation of CDTT	Sumit Mukhopadhyay
4:00 PM	Instrumentations in the CDTT : Discussion led by	Robin Datta
4:30 PM	Adjourn	