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NCS

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Ninth Thermal Workshop (20.01402.661and 20.01402.671))

DATE/PLACE: November 3, 1999
Albuquerque, New Mexico

AUTHOR: D. Hughson and S. Hsiung

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AUTHOR: D. Hughson and S. Hsiung

PERSONS PRESENT:

D. Hughson and S. Hsiung attended from the CNWRA. D. Esh and D. Galvin attended from the NRC.

BACKGROUND AND PURPOSE OF TRIP:

The pre-licensing NRC interactions with DOE include staying informed of DOE site characterization activities. One of the review methods for the Thermal Effects on Flow Key Technical Issue, Issue Resolution Status Report (TEF KTI), Revision 2 (NRC, 1999) is to observe "DOE test planning and technical meetings, where results of testing activities are discussed." Thermal-mechanical effects on underground facility design and performance are also important for the Repository Design and Thermal-Mechanical Effects Key Technical Issue. It was for learning about the progress of ongoing DOE heater tests that NRC/CNWRA staff attended the Ninth Thermal Workshop.

SUMMARY OF PERTINENT POINTS:

SUMMARY OF ACTIVITIES:

The workshop was hosted by S. Sobolik, Sandia National Laboratories (SNL). Travel restrictions at Lawrence Livermore National Laboratory (LLNL) apparently caught the organizers of the Ninth Thermal Workshop by surprise. Several speakers on the attached agenda were absent, or participated by telephone, because of travel restrictions and the overall attendance was down to about 30. The Drift-Scale Test (DST), however, continues heating and generating interesting data.

S. Ballard, LLNL, presented thermal data through 31 October 1999. Total power output from the wing heaters was maintained at 128 to 138 kW. Four wingheaters are not operating. The rate of temperature increase recovered quickly from a few power interruptions, one as long as 5 days. Canister heater temperatures are close to 200°C. Air temperatures in the heated drift (HD) range from about 170°C at the far, concrete lined end and near the bulkhead (BH), to around 185°C in the middle. Air temperatures near the crown of the drift are higher than near the rib for the middle portion of the drift and are reversed at the ends of the drift. Temperatures around the BH reveal a complicated flow regime resulting from interactions of the HD with the atmosphere and ventilation system. Driftwall temperatures, crown to springlines, averaged 178.6°C on day 666 of heating. Borehole 175, which goes up and to the right in the fan at y = 39 m, shows two-phase heat pipe flow for 2m along the borehole beyond a 4m dryout zone. The y-coordinate is measured along the long axis of the HD from the BH. Temperature anomalies in boreholes 79 and 80 are showing a lot of interesting behavior. These boreholes parallel the HD about 1.5 m above the plane of the wingheaters. Steam rising through a fracture, at about y = 12 m, heats the rock adjacent to the fracture at early times when the rock is below boiling. These anomalies flatten out as the boiling isotherm passes and the formerly anomalous highs then become anomalous lows as liquid condensate draining through the fracture cools the adjacent rock. Temperatures in borehole 80 are oscillating wildly. Temperatures in one area go up as temperatures in another area go down, apparently indicating air/water vapor transport of heat along the borehole. A period of relative calm in these oscillations corresponded to placement of a packer in September and a spike in temperature marks the time of its removal. Anomalies were seen in other gauges, some that later failed.

Mechanical measurements in the DST are noisy and the first part of S. Sobolik's presentation was about trying to determine the cause. Orientation of Multiposition Borehole Extensometers (MPBX) boreholes appears to be important in looking at the causes of the noise. Boreholes collared at the crown of the HD have substantial oscillations in temperature and MPBX data while those collared in the invert do not, showing more of a steady increase in temperature and displacement over time with only a few oscillations around the boiling point (BP). Looking specifically at MPBX 5 (Borehole 149) which is collared at the crown and has thermocouples at meter length intervals, oscillations in the noise appear to go up below the BP and down above the BP indicating reflux of water inside the borehole condensing and draining. Similar behavior is observed in the other MPBX boreholes collared at the crown. However correcting MPBX displacement data for temperature eliminated only some of the noise, indicating that factors other than water reflux in the borehole may be responsible.

Correlation between Acoustic Emission (AE) events and MPBX events (step changes in calculated rock displacement) was poor. Of 76 AE events and 80 MPBX events from June of this year, only 1 pair can be associated. One AE event proceeded an MPBX event by 14 hrs with good spatial correlation.

B. Freifeld, LBNL, presented the active and passive monitoring data from the 12 hydrology boreholes. Temperature, pressure, and relative humidity (RH) are collected from intervals separated by pneumatic packers where air permeability measurements are also periodically measured. Two pneumatic packers, 59-1 and 60-4, have recently failed. Pressures in the borehole intervals generally follow the atmospheric signal with two interesting exceptions. Intervals 60-2 and 60-3, below the HD, showed a cyclic pressure buildup as water collected in the borehole. These intervals are now above boiling and are no longer collecting water. Boreholes 59 and 76, above the HD, are just entering the boiling region. An anomalous drop of about 5 °C in 78-4, may have been caused by water moving into the area. The adjacent interval, 78-3, was in a heat pipe for about 200 days. Interval 78-3 is about 8 m laterally and 4 m below the HD.

Air permeabilities in the hydrology boreholes are referenced to a pre-test baseline. Changes in fracture saturation due to moisture movement can then be detected by a change in air permeability relative to this baseline. B. Freifeld pointed out that zones closest to the collars tended to remain the same or trend higher and related this to the advancing ventilation drying front around the Access/ Observation Drift (AOD). Overall decreases in air permeabilities appear to be more significant below the HD than above. In interval 60-2, below the HD where plenty of water was collected, air permeability decreased to one tenth of its pre-test baseline. Permeabilities in boreholes farthest above the HD are scattered around their baseline values while in borehole 76, immediately above, and borehole 78 below the HD they also trend down to about one tenth of their baseline values. Borehole 186 has shown such complicated two-phase flow behavior that steady state air permeability measurements could not be achieved. Air permeability data from all boreholes at the end of June, excluding the zones closest to the collars, have a geometric mean reduced to one-fourth the original baseline value of $10^{-12.9}$ m^2, attributed to increase in fracture saturation. B. Freifeld judged the reduction in air permeabilities fairly extensive laterally, based on the cross-hole pressure responses during testing.

Due to the restricted travel policy, S. Blair presented the Electrical Resistivity Tomography Inversion (ERT) results and Self Potential (SP) data for A. Rameriz. The prominent wetting followed by drying "finger" below the HD, and closer to the BH, has become more amplified in recent data. Recall, the ERT boreholes have electrodes grouted at 1 m intervals. The ERT inversion uses each electrode as a transmitter and the rest as recievers, with temperature as input, to find saturation from resistivity via the Waxman-Smith model.

Self Potential between electrodes in boreholes above and below the HD about midway along its length, referenced to a ground in the AOD, show marked drop-off at the end of the wingheaters on the AOD side starting early and continuing. An SP of about 700 mV is positive in the borehole below the HD and negative in the borehole above. This rather dramatic observation in SP may be indicating a vertical fracture zone about 1 m past the wingheaters on the AOD side.

J. Peterson's cross-well Ground Penetrating Radar (GPR) data also show a fracture zone parallel to the HD between borehole 80 and the AOD. This fracture zone is seen in videologs of boreholes about 16 m from the collar in the AOD. Determination of saturation from GPR is hindered by the difficulty in finding the dielectric constant's relationship with temperature and saturation at high temperatures and high frequencies. GPR tends to be more accurate in detecting decreases, rather than increases, in saturation.

One hundred AE events have been recorded since January 1, 1999. Most events occurred above the drift and almost no events occurred below. AE events were registered before the Hector Mine earthquake but none for a week after.

R. Carlson presented data from the neutron probe access boreholes. Borehole 67 (N09) was the first one to show moisture movement. This occurred at 105 days of heating near the end of the wingheaters, at about the same location as seen in the GPR data. Borehole 68 (N10) was the next to show dryout around 357 days. Borehole 50 (N04), at 6.5 m from the BH, showed a little drying starting around 266 days of heating and took almost 4 months to get completely dry.

The longitudinal boreholes 79 (N11) and 80 (N12) are 4 inches in diameter and thus have more grout than the 3-inch diameter boreholes extending from the AOD. This grout has a large effect on the measured neutron count rate in these boreholes. The first indications of drying in borehole 79 (N12) were seen around day 336 but not until day 404 in borehole 80 (N12). Drying took several months. A zone apparently resistant to drying is seen around 23 – 24 m into the borehole, correlating with anomalous temperatures, and a zone around 45–50 m appears to be wetting. Water has begun collecting in borehole 80. A drying resistant zone in borehole 79 is seen in the same location as in borehole 80, indicating a through-going consistent feature at least 30 m long perpendicular to the fracture seen in the GPR data.

M. Conrad's presentation concentrated on recent gas sample analyses. Gas samples are collected approximately quarterly and there are a few questions about the way CO_2 concentrations are obtained. Carbon isotope ratios are used primarily to identify the source of CO_2 (i.e. pore water or dissolution of calcite). Low $\delta^{13}C$ isotope ratios appear in borehole 57-3, above the drift at about y = 10 m from the BH. This is postulated to be caused by increased CO_2 levels in a slowly heating low permeability zone. Concentration of CO_2 in borehole 59-3 has increased by 2 orders of magnitude over background levels to about 1.1%. This is in a reflux zone and the high levels of CO_2 may be due in part to calcite dissolution in the fractures. In the dryout zone below the HD, CO_2 concentrations are actually below ambient levels. The August 1999 data show CO_2 in borehole 59-4 up to 6.6%. The high $\delta^{13}C$ value of -2.5 per mil indicates that this high level of CO_2 must be due to dissolution of calcite. In borehole 76-4 concentrations of CO_2 reached 13% with $\delta^{13}C$ up to -1.3 per mil in the May, 1999 data. By August 1999 the CO_2 concentration began to level off and start down. In borehole 185-2, above the drift in the fan farthest from the BH, CO_2 concentration was 2.3% on May 1999, increasing to 3.2% by August 1999. Since temperatures were only up to around 40°C in May, this high concentration must be due to a high permeability fracture connection to a CO_2 producing zone.

Carbon isotope ratios in borehole 57-3 start out around -14 per mil and remain low even though CO_2 concentrations rise from 940 to 3300 ppm. In borehole 59-3, on the other hand, the carbon isotope ratio went from around -10 to -1 per mil as CO_2 concentrations rose from 840 to 12700 ppm. In the zone where dryout occurred very quickly in borehole 77-3, CO_2 concentrations jumped up to 33000 ppm then dropped again to 1100 ppm. Trends clearly seen in the data up to this point are that both CO_2 concentrations and $\delta^{13}C$ values increase with temperature. In the boiling zone CO_2 concentrations jump way up and, after the boiling zone passes, drop way down.

M. Conrad also gave E. Sonnenthal's, LBNL, presentation on coupled thermal-hydrological-chemical modeling of the DST. New features recently incorporated in the THC model include an active fracture model for flow, a modified active fracture model for kinetic reactions, pressure and temperature dependant CO_2 diffusion in the gas phase, a nonlinear rate law for silica precipitation based on the work of S. Carol (LLNL, 1998), coupling of matrix and fracture porosity, permeability, and capillary pressure to reactions, and the addition of F and Fe bearing aqueous phase species. There are 24 minerals accounted for in the model. Initial concentrations are based on analyses of pore water from cores. The match between model predicted and measured CO_2 concentrations was substantially improved by changing the boundary condition representing the BH. The new rate law for silica precipitation, based on the recent work by S. Carol, results in 3 to 4 times as much silica precipitation in the dryout zone. Model simulated precipitation of amorphous silica is now about 2 orders of magnitude greater than previously predicted, however the calculated change in permeabilities are still small. Maximum CO_2 concentration predicted by the model of around 78000 ppm is now closer to the maximum measured values, modeled CO_2 concentrations in the drift air of 400- 500 ppm are similar to measured values, and the minimum 6.6 pH of condensate in the model is close to the minimum measured values.

B. Marshall, USGS, presented results of U and Sr isotope analyses on the water samples collected from the hydrology boreholes. U concentration, in picograms per gram, decreases with time in the water collected from borehole 60-3. However these concentrations are so dilute the analyses are probably no good. The ratio of $^{234}U/^{238}U$ doesn't change much with time and is in the range expected for pore water. Groundwater at Yucca Mountain (YM) has an anomalously high $^{234}U/^{238}U$ ratio of about 6 while the bulk rock of YM has a ratio of about 1. Sr concentration also decreases with time, from about 300 down to 0 ng/g, over the period June 1998 to June 1999, in water samples from borehole 60-3. The ratio $^{87}Sr/^{86}Sr$ in these samples decreases from 0.7124 to around 0.71 then remains fairly constant through June, 1999. The low ratio in the last $^{87}Sr/^{86}Sr$ data point may be indicative of mixing with grout or fracture calcite, however there is no evidence for reaction with bulk rock minerals such as feldspars.

R. Datta informed us that part of the thermal processes AMR (Abstracted Models Report) involves using property sets other than the thermal-hydrological (TH) property set in model simulations of the Large Block Test (LBT), the Single Heater Test (SHT), and the DST to see how well these other property sets can be used to represent thermal processes. Y. Tsang spoke first about TOUGH2 simulations of the DST using the Unsaturated Zone (UZ) drift-scale property set. Temperatures are the bases for these comparisons. The UZ drift-scale property set uses the active fracture model whereas Y. Tsang has been using a fracture-matrix interaction parameter of 1 with the TH property set. Despite this reduced interaction between the fracture and matrix continua, simulations with the UZ drift-scale property set fail to show the two-phase flow heat pipe signatures in temperature around the end of the wingheaters in, for example, borehole 160. Notable differences between the TH and UZ drift-scale property sets are the fracture saturations, the TH property set having a much wetter ambient saturation, around 0.12, as compared to the UZ drift-scale property set's much drier 0.02 ambient fracture saturation. Also the UZ drift-scale property set tends to show a more symmetrical matrix saturation above and below the HD while the TH property set shows asymmetrically more drying in the matrix above than below the HD.

K. Lee spoke next, for T. Buscheck, about NUFT simulations of the DST using the UZ mountain-scale property set with the implicit dual permeability (DKM) conceptual model. Excessive numerical problems were encountered in these simulations such as poor convergence, excessive run-times, memory consumption, etc. Greater buildup in matrix saturation is seen below the HD than above in these simulations. Temperature comparisons along individual boreholes generally show under-prediction above the HD and over-prediction below the HD. Simulations have two-phase flow zones above the HD that are not seen in the vertical borehole data and borehole data below the HD show two-phase flow behavior not seen in the simulations. K. Lee continued with a presentation of the results of modeling the LBT using the UZ mountain-scale property set. He indicated that in general these simulations tend to underestimate dryout and over-predict temperatures.

N. Francis was to have spoken about DKM active fracture modeling of the SHT comparing again only temperature results from various property sets. However he hadn't prepared. Instead R. Datta led a discussion of models and property sets.

T. Buscheck (by telephone) had a general comment about temperature predictions. "One of the most sensitive parameters we could be adjusting is fracture spacing", he said. T. Buscheck thought that too much spacing between fractures would be overly restrictive to gas phase flow through the matrix blocks as they heat up. Thus during the thermal transient the BP would be increased due to the high gas pressure and temperatures would be high along with saturation. Y. Tsang responded, "Tom, I don't follow you at all" and went on to say that the active fracture model implicitly includes all of the fracture spacing information in the Van Genuchten alpha parameter. The ensuing discussion revealed either a difference in model implementation between the NUFT and TOUGH2 codes or a misunderstanding between the respective investigators.

B. Freifeld commented that temperature was probably not the best basis for comparison between the various property sets because the thermal conductivities are fairly similar while the hydrological properties are more dissimilar. Mountain-scale fracture permeability in this unit, for instance, is two orders of magnitude greater than the drift scale fracture permeability. Perhaps, he suggested, flux through a plane would be more appropriate since we are interested in processes such as suspension of moisture in reflux columns above the HD.

The subject then changed to the effect mass and heat loss through the BH had on the models. Y. Tsang said that, based on temperature comparisons, the real system was losing 22 kW per year through the BH. She bases this on the model's over-prediction of temperatures and implementation in the model of the BH as a perfectly insulated boundary. Someone asked K. Lee if LLNL had arrived at a similar conclusion and he replied that they had implemented the BH as a permeable boundary with a thermal conductivity of 0.042 $W(mk)^{-1}$.

S. Blair brought up the question of the AMR supplying performance assessment (PA) and the multi-lab comparison study of the various property sets. R. Datta replied that these were the data sets already in use by PA and the comparison was for impact analysis, that is, are they appropriate for the thermal pulse and, if not, then what's the impact?

R. Wagner thought the DST data clearly show that water does not perch above the HD and underneath the HD rock is wetter. So how did the water get there, he wondered, did it flow around and come back under? Y. Tsang disagreed that this conclusion could be made given the existing data. R. Datta pointed out that all of the moisture measurement techniques work better for drying conditons than for high saturations. T. Buscheck thought it would still be a good idea to model the wingheaters discretely on a fine grid to see if there could be flow between them.

L. DeLoach arrived mid-afternoon just in time to present the latest aqueous chemistry results from the DST. Water samples have been collected from hydrology borehole intervals 60-1, 60-2, 61-3, 186-3, 59-2, 59- 3, and 59-4, SEAMIST boreholes 55, 56, and 73 below the heaters and 54 and 71 above the heaters. Recently borehole 80 parallel to the HD has begun producing water. Well-characterized swipes were originally wrapped around the logger in borehole 80. However several liters of water have collected in this hole providing plenty of samples for analyses. Analyses of samples from borehole 80 are very dilute, especially in Si, indicating this water is condensate that has not interacted with the rock. Samples from borehole 59-4, above the drift, are distinct and believed to be contaminated. Huge amounts of Ca and Cl are seen in several samples. The possibility of grout contamination was investigated by leaching grout in the lab. Very high values of K concentration were seen in the grout leachate samples, however, and very little K is seen in the borehole samples. This along with NO_2, seen in grout but not in DST samples, effectively eliminates grout as the source of the contamination. The grout was sampled from Alcove 5 and heated with deionized water for several days. Another sample was kept at room temperature. The pH went from 6.65 to 12 in 3 days. Total organic carbon derived from the grout was around 125 mg/kg. High temperature leaching of the grout produced a leachate with high concentrations of K and SO_4 and some NO_2. Water chemistry analyses from SEAMIST holes are similar to hydrology holes except for higher Si concentrations of around 400 mg/L. Laboratory tests prove the SEAMIST rubber liners introduce Si, contaminating these samples.

Pore water chemistry is concentrated in Ca, Si, and Na with about equal amounts of Cl and SO_4 and a pH in the range of 7.6 to 8.4. DST samples are dilute by comparison with pH in the range of 6.8 to 8.0, consistent with condensate-fracture mineralogy interaction. Results from borehole 59 are distinctly different and presumed to be contaminated. The source of this contamination, however, remains unexplained.

R. Wagner presented the topic of heat and mass loss through the BH as a summary of the attached Interoffice Correspondence (IOC), with reference to the recently released IRSR. "We agonized over this in the planning stage", he said. Heat and mass loss through the BH was subsequently discussed at three thermal workshops and became a topic of an Appendix 7 meeting in Las Vegas, 28 April 1999. Conductive heat loss was measured on the BH surface at 5 locations to be on the order of 5 to 7 kW. Convective heat loss, however, was deemed more significant. Something like 35 L/hour of water is estimated going into a 50 to 150 million L/sec ventilation duct. What about shutting the ventilation off temporarily in order to do a controlled test, as suggested by B. Freifeld and S. Ballard? Instruments sufficiently sensitive to low flow rates are intended for laboratory environments and are inadequate, according to R. Wagner, for measuring air flow through the BH. At this point both S. Ballard and B. Freifeld interrupted to say that flow measurements were not required. Their suggestion was to monitor the transient response of temperature and RH in the AOD, and back out the BH response from a volume averaged energy balance. Apparently this misunderstanding was overlooked in the review of the IOC. The discussion quickly focused on how representative a test with the ventilation off would be of conditions existing when the ventilation was on. Opinions ranged from "at least it's a stab" to "a hundred times different, not even relevant".

The IOC contends that loss through the BH can be dealt with numerically. Comparisons of simulated and measured temperatures are pretty good even within 1 m of the BH. In conclusion R. Wagner said there's pretty good control on the responses so there's not a big incentive to go after measuring convective heat losses because of the associated complications. S. Ballard pointed out that it's difficult to use data to confirm your model then turn around and use your model to confirm the data. This is seen as circular reasoning he noted. R. Wagner agreed but countered that "there are tradeoffs and we'll not be in utopia regardless"

Robin Datta concluded with a brief update on DECOVALEX.

CONCLUSIONS:

It is still too early in the DST to draw conclusions on the nature of TEF in the near-field.

PROBLEMS ENCOUNTERED:

A point we tried to make at the 28 April 1999 Appendix 7 meeting, without success apparently, was that mass loss through the BH due to ventilation may mask some two-phase flow features above the HD that might otherwise be observed. Now DST data apparently show less saturation above the drift than predicted by their models. However, a reduction in saturation and two-phase flow above the HD is what our models predicted would occur due to ventilation.

PENDING ACTIONS:

None

RECOMMENDATIONS:

Simulations performed prior to the 28 April 1999 Appendix 7 meeting with and without ventilation should be repeated in more detail, specifically looking at the effect of ventilation on liquid saturation and the formation of heat pipes above the HD. Subissue 1 of the TEF KTI IRSR concerns the sufficiency of the DOE thermal-hydrological testing program to evaluate the potential for thermal reflux to occur (NRC, 1999). If our models indicate that ventilation and mass loss through the BH may be reducing reflux above the HD and may be partially responsible for the apparent asymmetry of the observed dryout zone, these results should be communicated to the DOE.

REFERENCE

U.S. Nuclear Regulatory Commission, Issue Resolution Status Report (Key Technical Issue: Thermal Effects on Flow, Revision 2), August, 1999.

SIGNATURES:

Debra Hughson

Debra L. Hughson
Geohydrology and Geochemistry

18 Nov 1999
Date

for S. Hsiung

Simon M. Hsiung
Mining, Geotechnical, and Facility Engineering

11/18/99
Date

CONCURRENCE:

Asad Chowdhury, Manager
Mining, Geotechnical, and Facility Engineering

11/18/99
Date

Budhi Sagar
Technical Director

11/19/99
Date

ATTACHMENT 1

Agenda

9^{th} Thermal Test Workshop
Albuquerque, New Mexico
November 3, 1999

There will be a thermal test workshop in Albuquerque, New Mexico on Wednesday, November 3 1999 to discuss the results to date from the thermal tests. The workshop will be held in the Conference Room West of the Co-operative Monitoring Center on Eubank Blvd., Albuquerque, just outside the Kirtland Airforce Base. We will follow the agenda given below :

Wednesday, November 3, 1999

8:15AM	Welcome and introductions	Ray Finley

DRIFT SCALE TEST

8:20 AM	Drift Scale Test thermal measurements (temperature and heater power)	Sandy Ballard
8:45AM	Mechanical measurements	Steve Sobolik
9:10 AM	Hydrological active testing and passive monitoring	Yvonne Tsang
9:35 AM	ERT measurements in the DST	Abe Ramirez
10:00 AM	GPR measurements &acoustic emissions in the DST	John Peterson
10:25 AM	Break	
10:40 AM	Neutron logging measurements	Richard Carlson
11:00 PM	Analyses of water samples from the DST	Laura DeLoach
11:25 PM	Gas and water sample analyses	Mark Conrad
11:50 PM	Lunch	
1:00 PM	Sr/U Isotopic analyses of DST water samples	Brian Marshall
1:20 PM	Thermal- chemical Interpretive analysis of DST	Eric Sonnenthal
1:40 PM	Thermal Test AMRs	Robin Datta
1:45PM	TOUGH2 simulation of the DST with UZ drift scale property set	Sumit Mukhopadhyay
2:10 PM	NUFT simulation of the DST with UZ drift scale property set	Tom Buscheck
2:35 PM	Simulating the SHT with UZ drift scale property set	Nicholas Francis
2:55 PM	Break	
3:10 PM	Simulating the Large Block Test with	Ken Lee

UZ drift scale property set

3:30 PM	Drift scale property set for thermally perturbed flow – Discussion	Robin Datta (lead)
4:00 PM	Heat loss through the bulkhead	Ralph Wagner
4:20 PM	DECOVALEX III	Robin Datta
4:35 PM	Any other item	
5:00 PM	Adjourn.	

ATTACHMENT 2

Interoffice Correspondence (IOC)

DRAFT DISCLAIMER

Interoffice Correspondence
Civilian Radioactive Waste Management System
Management & Operating Contractor

TRW

TRW Environmental
Safety Systems Inc.

QA:QA

Subject:
Assessment of Heat Loss Through the Drift Scale Test Bulkhead

Date:
October 21, 1999
LV.NEPO.TEST.RAW.10/99-373

From:
R. A. Wagner
Ralph Wagner

To:
M. T. Peters

cc:
See Below

Location/Phone:
SUM1/820B
702-295-5623

BACKGROUND

Over the past several months, the issue of heat loss through the Drift Scale Test (DST) bulkhead has been discussed and analyzed. Much of this discussion has been documented in three informal reports entitled "Thermal Test Progress Report No. 1, 2, and 3" (see Enclosure Nos. 1, 2, and 3). The issue of heat loss was initially addressed during the design of the bulkhead in which it was not considered necessary for the heated drift to be sealed air tight (DST Design and Forecast Results report; BAB000000-01717-4600-00007; published December 11, 1997). Rather, the bulkhead was to be protective and to serve as a primary thermal barrier to retard conductive heat loss. This type of bulkhead would allow workers and visitors close access to the DST with minimal risk. In addition to internal discussions among the thermal test team, the NRC requested a U.S. Department of Energy/Nuclear Regulatory Commission (DOE)/(NRC) Appendix 7 meeting to further discuss this topic. This meeting was held April 28, 1999 in Las Vegas. A summation of the meeting was circulated by e-mail on June 13, 1999 by Michael Scott (see Enclosure No. 4). Key issues related to bulkhead heat loss raised by the NRC are as follows: continuously monitoring vapor and air escaping the bulkhead; evaluating the efficacy of redundant calibrated manometers; and evaluating existing ventilation data in assessing heat loss.

SUMMARY/RESULTS

In summary, the original plan/design of the DST bulkhead is still considered satisfactory. The bulkhead was simply intended to provide a protective and primary thermal barrier to allow personnel, both visitors and workers, to observe the heated drift and to work in close proximity to the bulkhead/heated drift with minimal risk. After much additional scrutiny, extensive and more accurate characterization of the heat loss through the bulkhead is considered difficult, problematic, and unnecessary.

Heat loss is attributed to a combination of the three primary modes of heat transfer: conductive, convective, and radiative. Determination of the total heat loss or individual modes of heat transfer is nontrivial for several reasons including:

- Convective Heat Loss
  - irregular shape of the bulkhead (regardless, conductive heat loss is considered small compared to convective heat loss).

- Convective Heat Loss
  - the inherent leakage through the bundles of power-cables and instrument-wiring pathways through the bulkhead,
  - substantial ventilation on the cool side of the bulkhead greatly impedes the ability to measure heat loss from the bulkhead,
  - the inability to measure low airflow rates should the existing ventilation be greatly reduced,
  - existing ventilation data is not useful for determining heat loss because large volumetric flowrates and limitations of temperature and relative humidity measuring devices, and
  - because of problems cited above, continuous measurement would not be beneficial.

- Radiative Heat Loss
  - with the exception of a minor amount of radiation through the glass windows, radiative heat losses is primarily from the outer surface of the bulkhead. Given this condition, it is a subset of conductive heat loss and can be considered both difficult to measure and a minor component of the overall heat loss.

Ultimately, the need to measure heat loss through the bulkhead hinges on the accuracy of numerically simulating the thermal behavior in the DST. Analyses indicate that an assumed convective boundary condition results in good comparative agreement between measured and simulated temperatures. Thus, the lack of accurate measurements of heat loss can be offset by proper numerical modeling. This approach is preferable to attempting to directly measure heat loss which has proven to be difficult.

DISCUSSION

The following discussion on heat loss through the bulkhead is divided into the three modes of heat transfer losses and an evaluation of a numerical approach to this problem.

Conductive Heat Loss

Much discussion on addressing conductive heat loss through the bulkhead has been documented in three informal progress reports (see Enclosures Nos. 1, 2, and 3). The following is a summary of the approaches and results presented in these informal reports.

Conductive heat loss through the bulkhead initially appeared to be a significant contributor to the total heat loss. Also, it appeared a remedy, insulating the cool side, could be easily and effectively installed. Before insulating, attempts were made to quantify the conductive heat loss by direct measurements. Subsequently, heat flux through seven steel and glass locations was measured with heat flux meters. The total conductive heat loss, based on these measurements, was estimated to be approximately 6 kW. The irregular shape of the bulkhead, especially numerous "fins" or steel-mesh guards that protect the glass windows, make it difficult to accurately extrapolate these conductive heat flux measurements into a single value. Because of the inherent uncertainty to these measurements, the estimate that conductive heat loss is much less than convective heat losses, and newly perceived problems with the installation of insulation; further evaluation of heat loss was focused on convective heat loss.

Radiative Heat Loss

Heat loss through the bulkhead by radiation was not considered because it cannot be measured without good measurement of temperature along the outer side of the bulkhead. As discussed above, the irregular configuration of steel, windows, and cable/wire bundles makes this a formidable and difficult task. Most radiative heat loss is a component of conductive heat loss since the conductive heat loss is dependent on temperature difference across the thickness of the bulkhead materials (e.g. steel plates or glass windows); whereas, radiative heat loss is dependent on the temperature difference between the bulkhead's outer surface and the air. A secondary amount of radiative heat loss is transmitted through the bulkhead's glass windows which comprise a small fraction of the bulkhead's surface area. In summary, most of the radiative heat loss is a subset of the conductive heat loss and therefore is not considered significant.

Convective Heat Loss

As discussed in Enclosures Nos. 1, 2, and 3, measurement of convective heat loss is difficult for several reasons. The leakage through the three sets of power cables and single set of instrument wiring is essentially unstoppable. Other leaks exist around the periphery and through door and window openings. Attempts to pack and seal the bundles and other leaks have only mitigated, not eliminated, this uncertainty. Another factor is the temporal moisture fluctuations from "barometric pumping" and the dynamics of moisture drying and mobilization in the heated drift and test block. These temporal fluctuations, which are both diurnal and seasonal, are difficult to eliminate because continuous measurements of convective heat loss are not practical.

Whether the convective heat loss is measured from either a liquid-water condensation/collection system or a water-vapor relative humidity detection system, inherent uncertainties will be substantial. Other concepts for measuring convective heat loss through the bulkhead are considered even less applicable. The primary problem with the liquid-water condensation/ collection system is (1) the collected sample does not represent the total amount of water vapor loss and (2) the inability to accurately estimate the total amount of water vapor loss. Also, continuous measurements, which would be expensive and cumbersome, would be needed to avoid uncertainties from temporal fluctuations.

The primary problem with the water-vapor relative humidity detection system is the need to reduce the flow of ventilated air on the cool side of the bulkhead to ensure an accurate determination of the amount of water vapor escaping through the bulkhead. The need to significantly reduce the ventilation rate becomes apparent when the rate of moisture loss from the numerically estimated 22 kW convective heat loss (equates to 35 liters of water vapor per hour which requires 1.5 million liters of air per hour to keep the air saturated) is compared to the range of ventilation flow rates between 50 and 150 million liters per hour. This comparison indicates the ventilation rate is 35 to 100 times too large to allow estimation of moisture loss through the bulkhead by measuring relative humidity changes. [Note: Thermal-hydrological analyses by LBNL indicate convective heat loss through the bulkhead is approximately 22 kW].

Complications also exist with accurate measurement of a much slower ventilation flow rate needed to detect the moisture losses through the bulkhead. Based on input from an M&O ventilation analyst, Romeo Jurani, devices available to detect low velocities are listed below along with respective minimum velocities needed for measurement:

- Anemometers (0.15 m/s)
- Hot-wire anemometers (0.07 m/s)
- Manometer (0.50 m/s)
- Smoke tester (0.05 m/s)...Note: requires diameter of air pathway to be less than 0.5 m

All of these minimum velocities are higher than the maximum velocity (0.02 m/s) needed to detect moisture losses in the 5-m-diameter drift outside the bulkhead.

Ron Green, CNWRA, requested the thermal test team to investigate flowmeters for low flowrates. Specifically, he found a flowmeter distributed by J&W Scientific capable of measuring 10 ml/min. Upon contacting a technical support member, Jason Ellis, it was explained that J&W Scientific flowmeters were designed for application in a laboratory environment for small diameter tubes. Mr. Ellis explained that the technology in their flowmeters would not be applicable to large-diameter tunnels such as those in the DST. Mr Ellis suggested contacting Omega Engineering for low flowrate flowmeters. Omega Engineering technical support member, Gary Palmer, confirmed that it would be difficult to measure velocities lower than 0.05 m/sec. Furthermore, he said spatial variability in flowrate and direction would make it quite difficult to interpret measurements at these low flowrates. Even if the reduced flow of ventilated air could be measured and resulted in a reasonable estimate in moisture loss, the reduced air flow is not representative of actual conditions. Actual ventilation velocities are estimated to range from 0.70 to 2.1 m/s. But as discussed above, these higher velocities make it essentially impractical to measure slight increases in relative humidity from moisture losses through the bulkhead.

Numerical Simulations

Ultimately, the need to directly measure the heat loss through the bulkhead is related to its impact towards producing accurate numerical simulations. Based on qualitative (see Figures 1 thru 3) and quantitative (see Table 1) comparisons of measured and calculated temperatures, it appears additional accuracy in characterization of the bulkhead will not significantly improve the ability to simulate the thermal response in the DST block. Figures 1 thru 3 show good agreement in both temperature magnitude and trend for six representative locations approximately one meter into the rock along the heated drift. In general, the calculated temperatures are slightly greater than measured temperatures. This could be further reduced by modifying the "perfectly-insulated" boundary condition along the bulkhead to allow some conductive heat loss.

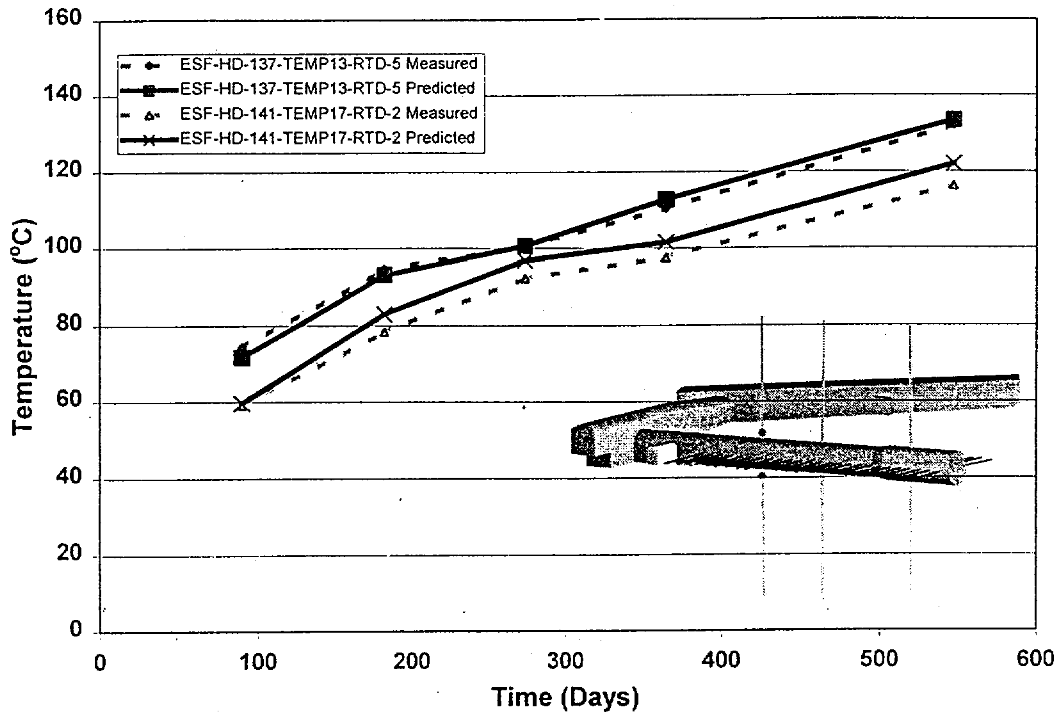

Figure 1. Comparison of Measured and Calculated DST Temperatures approximately 12 meters into the Heated Drift and One Meter into the Roof.

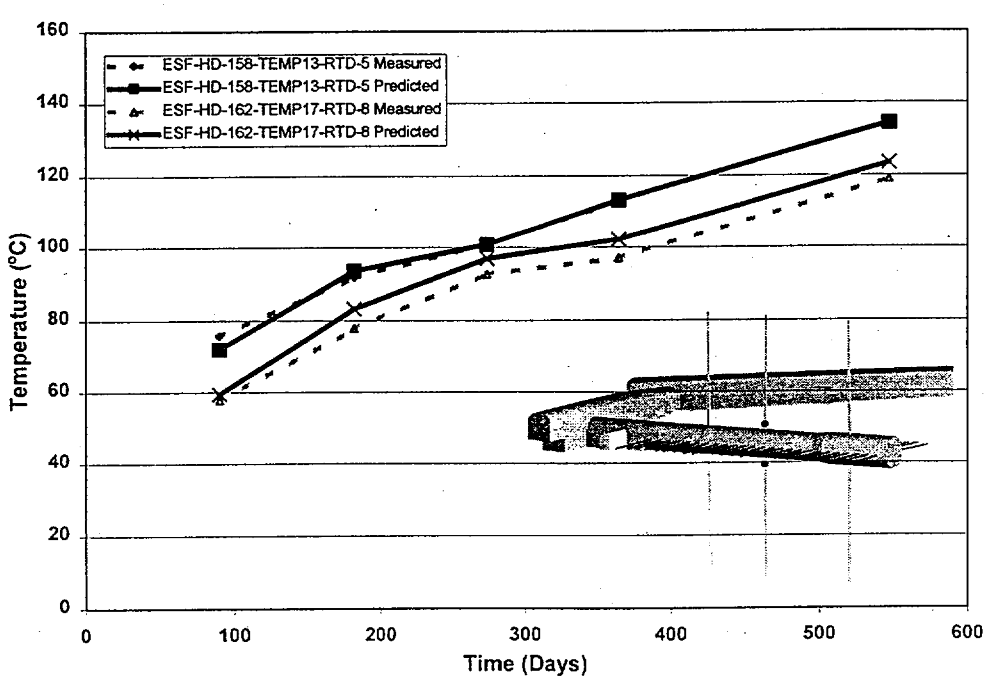

Figure 2. Comparison of Measured and Calculated DST Temperatures approximately 23 Meters into the Heated Drift and One Meter into the Roof.

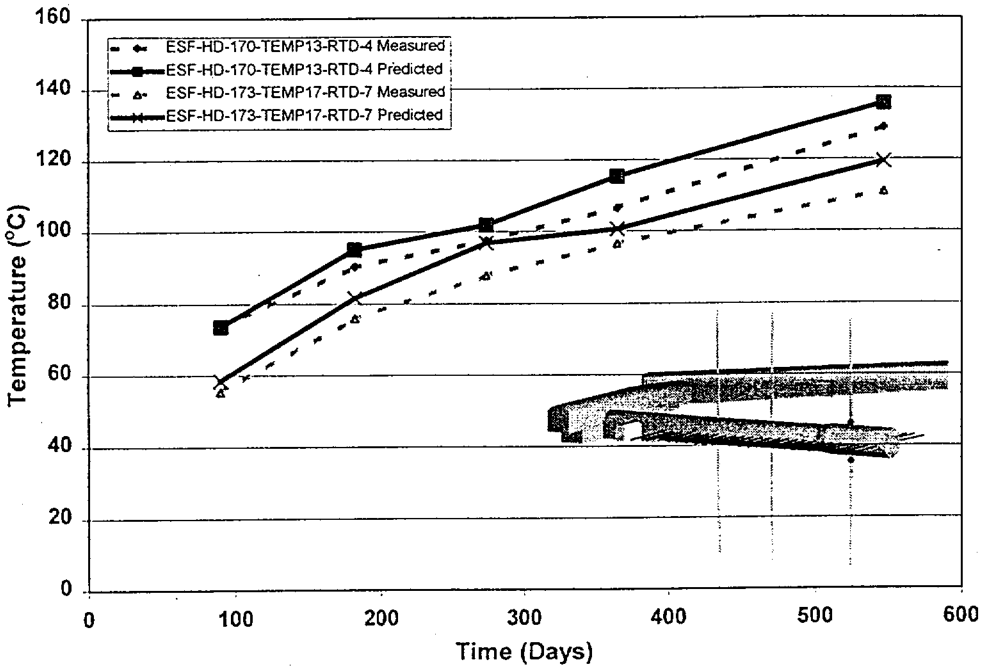

Figure 3. Comparison of Measured and Calculated DST Temperatures Approximately 39 Meters into the Heated Drift and One Meter into the Roof.

Statistical measures, such as weighted root mean square error (WRMSE) and mean error (ME), shown in Table 1 indicate good overall agreement between measured and calculated temperatures throughout the DST block. Approximately 1500 thermal measurements from 23 boreholes were used in this statistical assessment. The thermal-hydrological calculations are from an effective continuum, three-dimensional model of the DST. The ME ranges from +0.8 to +3.2 °C during the initial 18 months of heating. The WRMSE ranges from 4.3 to 8.7 for the same duration. A positive mean error, which is small in this assessment, indicates a slight overprediction of the measured temperatures.

Table 1. Statistical Measures of Agreement Between Measured and Calculated Temperatures for Effective Continuum Model

Criteria	Time (months)					
	3	6	9	12	15	18
Mean Error (°C)	0.9	1.1	1.6	2.1	2.7	3.4
Weighted Root Mean Square Error (°C)	4.3	5.9	7.0	7.8	8.6	8.7

Note: Mean Error from simulated and measured temperatures of 23 boreholes (133, 137-144, 159-163, 165, 168-175) in the Drift Scale Test.

Since past numerical simulations and corresponding assumptions along with anticipated future refinements to the numerical analyses can account for the heat loss through the bulkhead, direct and difficult measurements of conductive and convective heat loss are not considered necessary.

RAW/dm

Enclosures
1. Moisture Movement Across the Bulkhead
2. Heat Lost Through the DST Bulkhead
3. Conduction and Convection Through the DST Bulkhead
4. DOE/NRC Appendix 7 Meeting on Thermal Testing

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RPC=20 Pages

4.11 Moisture Movement Across the Bulkhead

The Heated Drift is separated from the rest of the thermal testing facility by a bulkhead. The bulkhead is a thermal bulkhead, not a pressure bulkhead. It is made of a steel frame and steel plates and carries the lighting fixtures, viewing windows and the camera door. The bulkhead is insulated on both sides by fiber glass insulation pads.

The relative humidity (RH) inside the Heated Drift dropped to approximately 15 percent during the first 10 days of heating. Thereafter, the RH inside the HD fluctuated between 10 and 25 percent with a peak to peak interval of approximately 4 days. Measured RH in the HD has been inversely tracking the air pressure in the drift. After some forty days of heating, moisture started to flow out of the Heated Drift as evidenced by condensation on various surfaces near the bulkhead and the formation of a puddle on the floor. Such wet conditions near the bulkhead alternated with dry conditions with the latter coinciding with low RH inside the HD.

The Drift Scale Test System, comprised of the HD and the surrounding heated and unheated rock, is not a closed system. The DST block is exchanging moisture and air with its surroundings through the bulkhead and the fractured rock. Outflows coincide with higher RH in the HD and lower barometric pressure.

As the rock immediately surrounding the drift is heated to above the boiling temperature, the pore water in the rock is mobilized and driven outward creating a dry-out zone around the drift. As the mobilized water in the vapor phase moves outward, it condenses when it reaches cooler regions and vaporizes again, as additional thermal pulse reaches it. A boiling zone is thus formed around the dry-out zone. Phase changes occur continuously in the boiling zone causing pressure to build up. When the barometric pressure and the pressure inside the HD are high, steam and water is confined to the boiling zone. When the barometric pressure and the pressure in the HD drop, steam and water escape from the boiling zone moving into the HD via the fractures and causing the RH in the drift to rise, much like what happens in pressure cooker or geyser.

Ways of measuring the heat loss through the bulkhead, both by conduction and convection, have been investigated. A pair of sensitive heat flux meters has been acquired and will be used to measure the heat loss by conduction in the first part of January 1999.

Measuring the loss by convection is difficult and complicated because flow takes place at numerous locations, at various rates and at different temperatures.

4.11 Heat Loss Through the DST Bulkhead

Heat loss through the DST bulkhead was investigated to obtain a better thermal boundary condition for numerical simulations of the DST. In some cases, the thermal boundary condition for the bulkhead was assumed to be perfectly insulated which translate into no heat flux. Given the understanding of the insulation thickness and condition on the "hot" side of the bulkhead, it became apparent that the heat flux through the bulkhead was significant.

The determination of the total heat flux required consideration of both conductive and convective modes of heat transfer. Radiation through the bulkhead was considered negligible. Conductive heat flux was determined with direct (non-Q) measurements by applying a heat flux meter to the seven locations on the bulkhead (see Figure 4.11-1). Five measurement locations were steel (Nos. 1, 2, 4, 5, and 7) and two measurement locations were glass (Nos. 3 and 6). Figure 4.11-1 shows these seven locations and the corresponding heat fluxes in W/m^2. Measurements of all seven locations were conducted with and without 4-inch thick insulation covering the heat flux meter. For location No. 1, three thicknesses of insulation were used (2, 4, and 6). By covering the heat flux meter with insulation, the influence of the nearby ventilation exhaust could be assessed.

Results indicate the mean conductive heat loss through the bulkhead is approximately 5 kW. Also, forced convection from the ventilation system increases conductive heat loss by approximately an order of magnitude. The 4-inch thick insulation appeared adequate to ensure the ventilation exhaust did not remove significant heat from the bulkhead.

Convective heat loss was estimated by considering how much water vapor was removed from a small diameter pipe in the bulkhead during a 60-minute sampling period. By considering the condensed water's heat of vaporization, it is possible to calculate the convective heat loss. Results from Table 4.11-1 indicate an approximate 0.5 kW heat loss. The total convective loss is dependent on the total pathways through the bulkhead including leakage along the periphery, doors, and wire/cable bundles. These total estimates indicate the convective heat loss through the bulkhead may vary from 2kW to 20kW. Because quantifying all pathways is difficult, accurate measurement of these type of losses is nontrivial.

Given the anticipated minor impact of these heat losses on the overall performance of the DST, remedies for reduction of heat loss should be straightforward, beneficial, and inexpensive.

Heat loss through the bulkhead accommodates, to some extent, the desire to keep the design thermal loading in the center of the DST block lower than the outer portion. This thermal load design increases the likelihood of observing reflux near and possibly into the heated drift during the cooling phase. Power was intentionally reduced in the floor heaters to 80 percent (54 kW) while maintaining the total power in the outer and inner wing heaters at 86 kW and 57 kW, respectively. Conversely, the heat loss across the bulkhead is nonuniform which would complicate proper modeling. Also, it is prudent, if feasible, to mitigate uncertainties.

Based on the above factors and much discussion among the thermal test team, the following actions were recommended.

- Re-pack the periphery of the bulkhead and other leaks to substantially reduce the amount of water vapor escaping through this pathway.

- Re-direct the ventilation such that it does not blow directly onto the bulkhead.
- If high-temperature spray foam can be located, spray into voids of the wiring and cable bundles to reduce vapor flow.
- Evaluate sensitivity of numerical predictions to the uncertainties associated with bulkhead heat losses.

Table 4.11-1 Convective Heat Loss Through the Bulkhead From Vapor Removal System.

DATE	AIR TEMP IN HEATED DRIFT (°C)	RELATIVE HUMIDITY IN HEATED DRIFT (%)	CONDENSATE RECOVERD (ml/hour)	CONVECTIVE HEAT LOSS (kW)
5 Aug 98	126	8.6	600	0.38
26 Aug 98	135	11.4	870	0.54
31 Aug 98	134	10.8	800	0.50

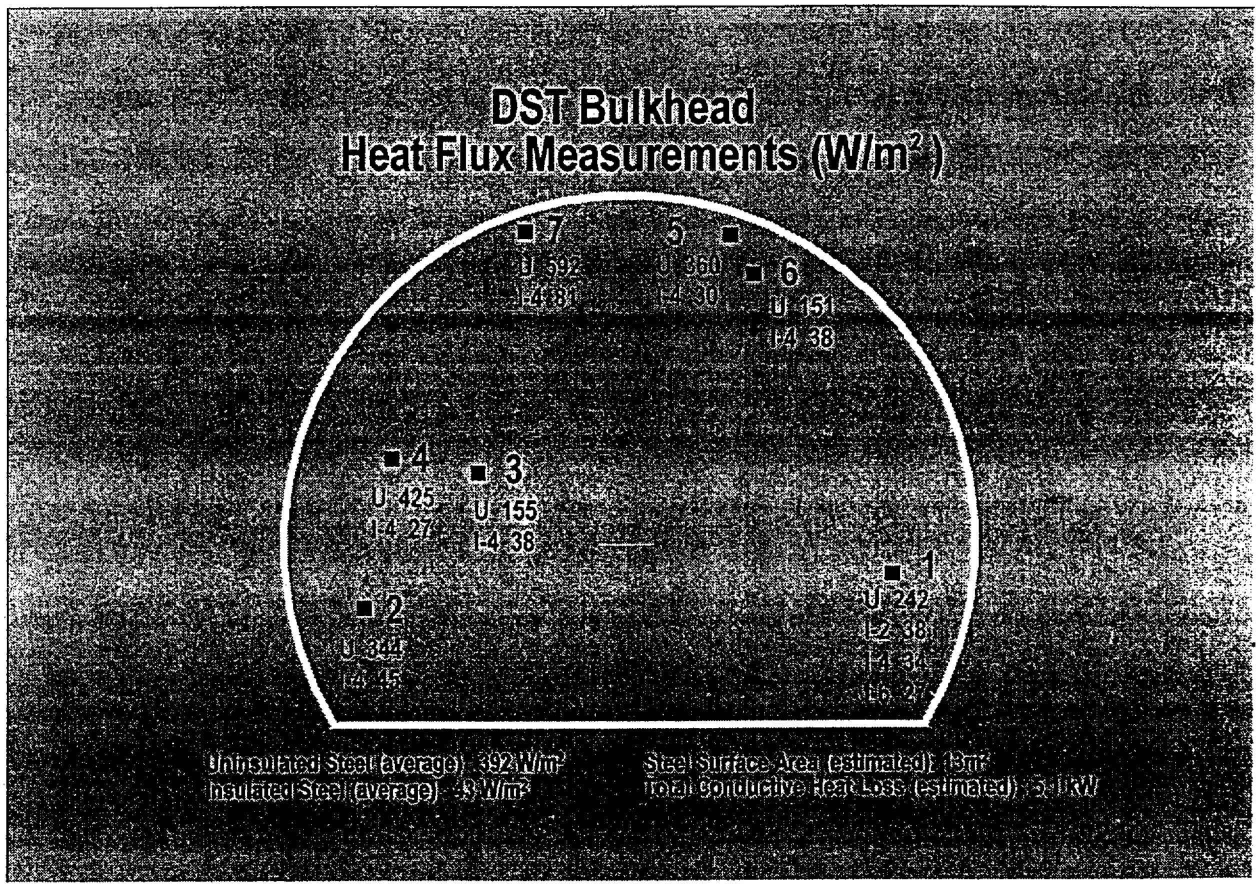

Figure 4.11-1 Heat Flux Measurements on the Bulkhead.

3.11 Conduction and Convection Through the DST Bulkhead

The loss of heat through the DST bulkhead has been an ongoing concern since the planning and design phases of the DST. Heat loss can be divided into conductive and convective fluxes. Conductive heat loss occurs through the bulkhead's steel construction; whereas the convective heat loss is from water vapor escaping through bulkhead leaks such as the power cables, sensor wiring, doorways, and periphery. It appears the measurement of convective heat fluxes is more difficult than the measurement of conductive heat fluxes. The following discussion provides a chronology of activities associated with the bulkhead's heat loss.

Design Considerations

The bulkhead was designed to perform as a thermal barrier but not as a hydrological barrier. Water vapor was not intended to be trapped. Even though the bulkhead was designed to be a thermal barrier, it was never intended to be perfectly insulated. Consequently, some heat loss was anticipated. This condition is considered acceptable because of the ability to numerically simulate the heat flux and limitations of constructing a thermal bulkhead.

Other design aspects of the DST need to be considered when evaluating the impact of heat loss through the bulkhead such as the existence of an open system in the DST block. An open system is known to exist because of the negligible retardation in barometric pressure between measurements in the local rock mass and the north portal pad. The existence of an open system in the fracture network provides implies numerous pathways, in addition to the bulkhead, for water vapor movement. The DST was designed to overdrive heating in order to expedite the test. This fast heating rate results in additional heat loss through the bulkhead. Also, it was anticipated that numerical simulations/modeling of the DST could accommodate uncertainties, such as bulkhead heat loss, through implementation of suitable boundary conditions and proper sensitivity analyses. Furthermore, the DST design anticipated the need for refinements in the test such as those associated with bulkhead heat loss.

Initial Observations

Shortly after the DST heaters were activated, moisture accumulations on the bulkhead's cool side were observed. Investigations of this phenomenon resulted in an understanding that the moisture was largely condensed water vapor that escaped the bulkhead. The observed moisture, estimated to be 100s of liters, has been a small fraction of the estimated 10 million liters of water mobilized in the test block.

Figure 3.11-1 shows graphically another observation stemming from this initial observation which is the inverse relationship of barometric pressure and relative humidity measured in the heated drift. This "barometric pumping" retards the flow of water vapor through the bulkhead, which is a measure of convective heat loss, during high pressure days. Conversely, the flow of water vapor through the bulkhead increases during low pressure days.

These initial observations led to installation of additional thermal and moisture probes along the roof's centerline on the bulkhead's cool side. These instruments facilitate the interpretation of moisture accumulation on the outside of the bulkhead. Also, these initial observations provided insights on repository performance including the potential for natural removal of heat and moisture as well as the likelihood of low relative humidity in the heated drift.

Refinements

Several refinements in the DST have either occurred or are anticipated. Specifically, baffles have been placed over the ventilation outlets near the bulkhead to reduce the amount of forced convection on the bulkhead. Water vapor leaks in the bulkhead, such as those in the camera door and cable outlets, have been sealed to the extent practical. Sealing is intended to mitigate convective heat loss through the bulkhead. A water collection system was developed to estimate convective heat losses through the bulkhead. Currently, improved methods for measuring conductive and convective heat losses through the bulkhead are being evaluated.

Recent Observations

Conductive heat losses have been measured on four occasions as shown in Figure 3.11-2. Results indicate the estimated conductive heat loss through the bulkhead ranges from 5 to 7 kW. Similarly, convective heat losses have been measured from nine different samplings taken from the water collection system. As shown in Table 3.11-1, the convective heat loss through the 1.5 inch-diameter opening in the bulkhead ranges between 0.2 and 0.6 kW. Total convective heat loss is estimated to range from 4 kW to 30 kW. Other observations indicate the presence of a convection cell around the bulkhead and a transient drying trend in the heated drift.

Future Activities

Future activities include ongoing monitoring of the thermal-hydrological behavior in terms of measurements and numerical simulations. This activity includes sensitivity analyses to better determine the impact of heat loss through the bulkhead on the ability to replicate the T-H behavior. Also, existing methods for measuring conductive and convective heat loss through the bulkhead are being re-evaluated to improve accuracy.

Table 3.12-1 Convective Heat Loss from Vapor Removal System.

Date	HD Air Temp (°C)	Relative Humidity (%)	Air Pressure (KPa)	Condensate Removed (ml/hour)	Convective Heat Loss (kW)
07/29/1998	133	15.2	90.0	305	0.19
08/05/1998	126	8.6	90.4	600	0.38
08/26/1998	135	11.4	89.9	870	0.54
08/31/1998	135	10.8	90.3	800	0.50
11/10/1998	145	5.1	90.7	600	0.38
02/09/1999	159	7.7	90.1	700	0.44
04/19/1999	169	5.0	NA	290	0.19
04/21/1999	169	6.4	NA	700	0.44
04/22/1999	169	6.4	NA	705	0.44

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4 Pages

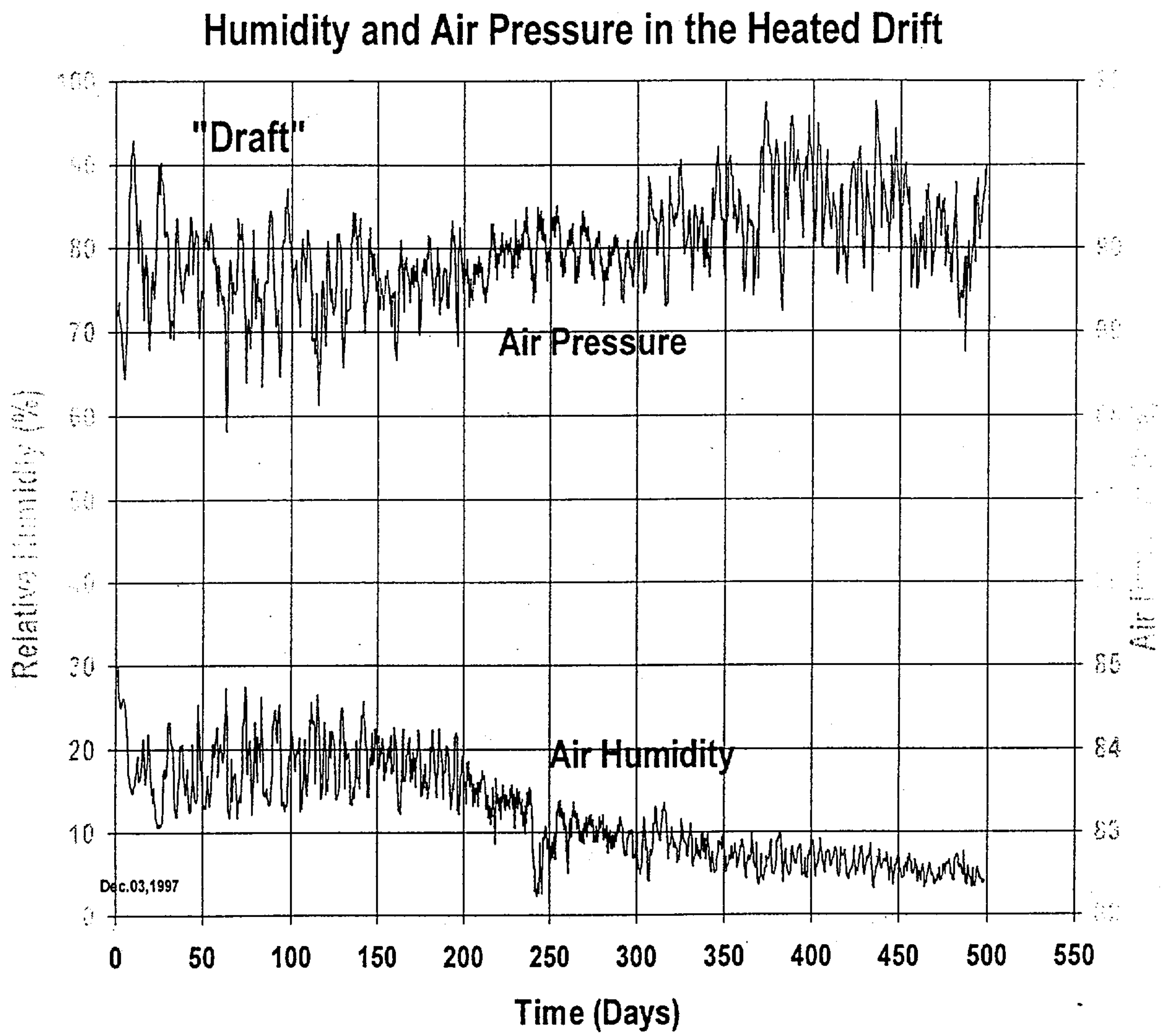

Figure 3.11-1 Inverse relationship of barometric pressure and relative humidity in heated drift.

Location	Heat Flux (W/m^2)			
	05-Jan-99	23-Mar-99	26-Apr-99a	26-Apr-99b
1	242	296	277	300
2	344	310	316	338
3	425	594	541	519
4	360	721	699	744
5	592	767	821	823
Est. Total Conductive Heat Loss (kW)	5.1	7.0	6.9	7.1

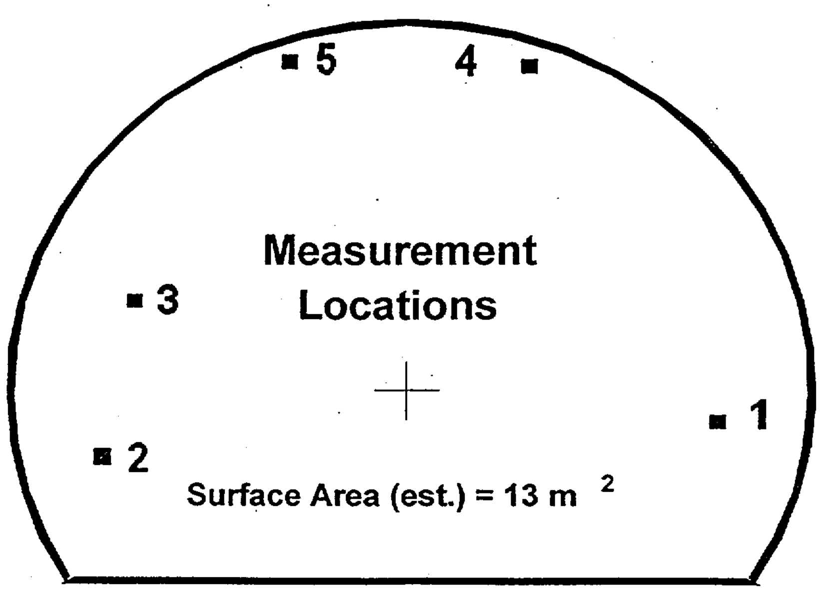

Figure 3.11-2 Measured covective loss on the bulkhead.

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Enclosure 4
5 Pages

DOE/NRC APPENDIX 7 MEETING ON THERMAL TESTING
Las Vegas, Nevada

April 28, 1999

Description of Meeting/Attendees

On April 28, 1999, staff from the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) conducted an Appendix 7 Meeting in Room 302 of the DOE Facilities at the Hillshire Bldg., Summerlin, Las Vegas to discuss thermal testing associated with the Drift Scale Test (DST). Participants included representatives from the NRC, the Advisory Council on Nuclear Waste (ACNW), the Center for Nuclear Waste Regulatory Analysis (CNWRA), the DOE Yucca Mountain Site Characterization Office (YMSCO), the Nuclear Waste Technical Review Board (NWTRB), and staff from the YMSCO Civilian Radioactive Waste Management System (CRWMS) Management & Operating contractor and Management and Technical Services contractor. The NRC technical lead was Brett Leslie. The DOE technical lead was Deborah Barr (U.S. Bureau of Reclamation (USBR)/DOE). No other stakeholders were represented. The agenda and the list of attendees are included in the records package and available electronically.

Presentation/Discussion Overview

D. Barr (USBR/DOE) and B. Leslie (NRC) made brief introductory remarks.

Unconstrained heat and mass loss through bulkhead and via ventilation and its impact on interpretation of results

J. Pohle (NRC) introduced the first topic: Unconstrained heat and mass loss through bulkhead and via ventilation and its impact on interpretation of results.

R. Green (CNWRA) presented a discussion on simulation modeling he had done using an analog scale model of a heated drift. Green noted that he would like to see monitoring of the amount of vapor and air escaping around the bulkhead in the DST. At this time, DOE does not have a good handle on how much mass is moving around the bulkhead. Green did note that with the repository design switch to Enhanced Design Alternative-2 (EDA2) some of his concerns went away (e.g., air pressure build up, as there will not be as much build up with the cooler design of EDA-2). At present the DST is not designed to detect dripping. R. Wagner (M&O) noted that the DST is overdriving the system six to eight times the heating compared to EDA-2 and three to four times the Viability Assessment (VA) repository design. This would suggest that there will be no dripping until the cool-down phase. W. Lin (LLNL) noted that the location of drips will be apparent when we go back into the DST. R. Datta (M&O) also noted that the camera could detect any dripping. Green indicated that in his model, the drips were caustic and actually destroyed the detectors. D. Wilder (LLNL) noted that this is not a good analog for the chemistry of the site as a concrete liner is no longer planned. Green agreed that the caustic chemistry was due to the concrete liner in the model. D. Barr (USBR/DOE) asked if the fractures in the model are realistic when considering the scale of the model. Green indicated the fractures were not to scale. Barr suggested that the scale of the fractures in the model would be a feature in the repository from which we would have a stand-off distance, and thus dripping from these features would not be a concern. Wagner noted that sporadic testing of vapor and air outflow around the bulkhead may not get an accurate picture. Green agreed, the outflow varies over time due to barometric pressure and other considerations. There should be constant monitoring.

D. Hughson (CNWRA) presented a discussion on her computer simulation modeling of the DST. The presentation was a reiteration of much of what was in the recent CNWRA report that she published with Green. The model was a dual-continuum model with a two-dimensional grid, smeared heat load and a horizontal temperature distribution.

R. Wagner presented a discussion on a Recap of Events and Activities regarding the heat and mass loss through the bulkhead.

T. Buschek (LLNL) presented a discussion on the impact on modeling. Much of this presentation was similar to that which was presented the day before in the thermal testing workshop. R. Datta noted that measuring heat on both sides of bulkhead will give more data. R . Wagner indicated that conductive heat loss was okay, the problem is convective heat loss. D. Barr noted that when considering any changes to the test, we have to differentiate between would be nice to have and what is essential to have. We need to determine what we can live with considering the budget. D. Wilder suggested that we need to balance the value of data lost versus decreasing uncertainty. There may also be cost savings associated with test changes. For example, it may cost initially to install insulation to reduce heat loss but this may mean that less electricity is needed to heat the DST to the required temperature. T. Buscheck noted that not much money is going to analyze the results of the test. B. Leslie emphasized that they were trying to get across the NRC concerns regarding the test; it is up to the DOE to decide what to do. D. Wilder asked whether, with EDA-2 now being preferred design and the DST being planned to look at the old proposed design, the Project should consider changing DST to bring it more in line with EDA-2. R. Datta suggested that this might be accomplished by shutting off the wing heaters.

Y. Tsang (Lawrence Berkeley National Laboratory [LBNL]) presented a discussion on the Effect of Heat and Moisture Loss Through the Bulkhead on the Interpretation of Results of the Drift Scale Test. Tsang noted that whether the heated drift bulkhead is considered an open or closed boundary does not affect the utility of the DST in evaluating the coupled thermal-hydrologic processes. The uncertainties in evaluating the bulkhead as a closed or open boundary are small compared to other uncertainties, such as heterogeneity. As an example of heterogeneity, Tsang cited fracture permeability, which can vary by three orders of magnitude and uses a geometric mean as a representative value. She noted that in two similar boreholes different temperatures were recorded. This is probably due to different fracture permeability in the holes. W. Lin suggested that water loss may affect coupon testing in DST. T. Buscheck noted that some water was also lost due to initial ventilation. D. Wilder noted that the system is not sealed, and he asked whether, if you had a sealed system, more water would go into the rock? Buscheck indicated more water would go into the rock and that water would not remain in the drift during the heating period, so the coupon test is all right as it is.

Discussion: R. Datta (M&O) began the discussion period by noting that he could not find a gage capable of measuring the small fluctuations necessary to assemble a convection monitoring method. R. Green suggested that redundant calibrated manometers can measure this. B. Leslie indicated that information on a supplier could be provided and Green volunteered to send this information via e-mail to Datta. Datta suggested that the Project has a good handle on what is going on at the bulkhead. To verify the amount of convective loss, the Project needs a monitoring system to assess air flow, temperature, and humidity. B. Leslie suggested that old ventilation data may provide some early or confirmatory data for air flow that passed the bulkhead.

<u>How are thermal-mechanical results being used to support repository design, and what additional thermal-mechanical data from other repository units will be collected to support repository design?</u>

B. Jagannath (NRC) introduced the next topic and introduced A. Ghosh (CNWRA) who provided a presentation on some concerns with the testing. The concerns involved:

- prediction of thermal-mechanical response observed at thermal tests
- applicability of the measurements to the proposed repository horizon as the measurements are being made in the middle non-lithophysal while 75% of the proposed repository horizon is in the lower lithophysal
- sufficiency of the thermal-mechanical data gathered for the repository horizon
- effects of alternative designs and how results from the tests are being incorporated into design.

Observation: The order of the Yucca Mountain Project personnel presentations was altered from the proposed agenda to allow a presentation on the data to be first.

R. Finley (M&O, Sandia National Laboratories) presented a discussion on The Available Data from the Tests. Finley noted that for the Single Heater Test, the final report contains much more data.

R. Wagner provided a presentation on additional Thermal-mechanical Data From Other Units. Wagner noted that whether or not the cross-drift thermal test is done or not depends upon the budget. D. Wilder stated that the design the Project is currently considering is different from the DST. This difference could be a driver for the cross-drift test. Wilder asked if this had been factored into the cross-drift proposal. Wagner indicated it hadn't, that much more planning is needed for the final proposal.

Rick Nolting (M&O, Repository Subsurface Design) provided a presentation on The Use of Thermal Test Thermal-mechanical Data by Repository Design. Nolting noted that any tests in the cross drift will be for performance verification after license application. A. Ghosh asked how in situ results are used versus lab results. Nolting indicated that the Project will use range-bounding values for design values.

W. Lin (M&O, LLNL; Note: Lin presented rather than D. Wilder who was listed on the agenda) provided a presentation on the Thermal-mechanical-hydrological Modeling in the Near-field Process Model Report.

Discussion: B. Jagannath suggested that another Appendix 7 meeting be held before the DOE finalizes plans for the Lower Lithophysal characterization. B. Leslie noted that the NRC does not get data in a timely fashion. He suggested that the principal investigators should check with Bill Boyle (DOE), as there may be a way to allow NRC to get the data quicker through some of the protocols for the International Decovelex.

<u>Water and gas sampling protocols and flow of information to and from Performance Assessment</u>

B. Leslie (NRC) introduced the concerns on this topic and noted that a focus should be placed on performance. What does Performance Assessment (PA) require? What are the constituents that control degradation? Predictions can't be made in PA unless we have constrained data. The primary user of data is PA. Leslie also raised the question of whether the sampling protocols are sufficient.

L. DeLoach (M&O, LLNL) provided a presentation on Aqueous Sampling and Chemistry in the Drift Scale Test. DeLoach noted that the Seamist system did not work as originally anticipated. B. Leslie asked if there was a work package that described the procedure. DeLoach answered that there was, but she thought the procedure was skimpy. She went to the field and observed the implementation of the procedure. She then wrote a more detailed procedure and may need to revise the procedure again to make it more detailed. It may be necessary to have the data taken by someone more knowledgeable. She also noted that the Seamist system was experimental. Some parameters are hard to sample for minimizing atmospheric exposure. Leslie suggested getting rid of the eight meters of hose. DeLoach stated that that is in the new protocol. Leslie noted that there are other methods that can be used. J Pohle (NRC) queried what is basis for tests. DeLoach answered that volume was. R. Wagner noted that this is an evolving issue; as the Project goes along and gains more experience, the procedure is revised. Leslie noted that the neutron holes have water in them and asked whether someone samples this water when the holes are logged. D. Barr stated that the chemistry is "screwy" in these holes due to concrete and other things (grouting, Teflon, etc.) in the neutron holes. R Datta said that the Project is considering converting chemistry holes. Y. Tsang said that the Project will convert chemistry/Seamist holes to two packed-off hydrology holes. Leslie indicated this would be great and asked if this will be permanently installed. Tsang answered yes. The Project will be doing this with lowermost chemistry holes.

E. Sonnenthal (M&O, Lawrence Berkeley National Laboratory) provided a presentation on Modeling of Thermal-hydrological-chemical Behavior. He discussed the pore waters and gas chemistries that could seep into the drifts. B. Leslie asked how sensitive fluoride is and whether it can tell you the fracture interaction. Sonnenthal said that it may give a fracture/matrix interaction. Different species may help provide estimates, especially the species U^{234}/U^{238}. Sonnenthal discussed that the model used is a dual permeability model incorporating mineralogy and aqueous species. M. Hamura (SNL) asked why PCO_2 is so small in model near the heater. D. Sassani (M&O) indicated that this was due to fractures being open and ventilation.

N. Francis (SNL) provided a presentation on Performance Assessment Operations Thermal-hydrological and Coupled Processes. R. Wagner asked Francis to detail flow of data to PA. B. Leslie said this was not necessary, that it was now clear on how the information flows to PA.

B. Leslie made closing remarks to state that he appreciated everyone's efforts and that this meeting was a very positive experience.

Assessment of meeting effectiveness

Based on Leslie's closing statement meeting was very effective in providing information to the NRC and addressing their concerns.

Commitments

No commitments are made at Appendix 7 meetings.

Observations

No additional observations were made beyond those discussed above.

New Issues/Concerns/Recommendations

None were noted.