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Account No. 20.01402.661

U.S. Nuclear Regulatory Commission
ATTN: Mr. Jeffrey Pohle
Division of Waste Management
TWFN, Mail Stop 7-D13
Washington, DC 20555

Subject: Administrative Item 01402.661.018, Comments on White Paper: Heat and Mass Flow Through the Bulkhead in the Drift-Scale Test, dated April 2001

Reference: Summary Highlights of DOE/NRC Technical Exchange and Management Meeting on Thermal Effects on Flow, January 8–9, 2001, Pleasanton, California

Dear Mr. Pohle:

The attached report provides staff comments on the white paper Heat and Mass Flow Through the Bulkhead in the Drift-Scale Test in accordance with agreement TEF 2.01 reached at the U.S. Department of Energy (DOE)/U.S. Nuclear Regulatory Commission (NRC) Technical Exchange on Thermal Effects on Flow held in Pleasanton, California, on January 8–9, 2001. Agreement TEF.2.01 states in part that "[t]he DOE will provide the NRC a white paper on the technical basis for the DOE's understanding of heat and mass losses through the bulkhead and their effects on the results by April 2001. ... This white paper will address uncertainty in the fate of thermally mobilized water in the DST and also the effect this uncertainty has on conclusions drawn from the DST results." This report satisfies the part of agreement TEF 2.01 that states, "The NRC will provide comments on this white paper."

The white paper is unequivocal in concluding that measurements of losses through the bulkhead of the DST are unnecessary. However, as noted in the trip report on the Twelfth Thermal Workshop held June 7–8, 2001, in Summerlin, Nevada, the DOE planned to begin making measurements of these losses in July 2001. The

DOE may intend to use these measurements to address the part of agreement TEF 2.01 that states, "[t]he DOE will provide analyses of the effects of this uncertainty [losses through the bulkhead] on the uses of the DST in response to NRC comments."

If you have any questions, please contact Dr. Debra Hughson at (210) 522-3805 or me at (210) 522-5151.

Sincerely yours,

Asadul H. Chowdhury, Manager
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AHC/ph
Enclosure

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COMMENTS ON WHITE PAPER: HEAT AND MASS FLOW THROUGH THE BULKHEAD IN THE DRIFT-SCALE TEST

Prepared for

U.S. Nuclear Regulatory Commission
Contract NRC–02–97–009

Prepared by

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CONTENTS

ACRONYMS

CNWRA	Center for Nuclear Waste Regulatory Analyses
CDTT	Cross-Drift Thermal Test
DOE	U.S. Department of Energy
DST	Drift-Scale (Heater) Test
FEP	features, events, and processes
NRC	U.S. Nuclear Regulatory Commission
TEF	thermal effects on flow
TH	thermohydrologic
TSPA	total system performance assessment
WRR	Water Resources Research

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA developed no original data for this project. Sources for other data should be consulted for determining the level of quality for those data.

CODE: No computer codes were used or developed in preparation of this report.

1 INTRODUCTION

The white paper, Heat and Mass Flow Through the Bulkhead in the Drift-Scale Test, was produced by the U.S. Department of Energy (DOE) in response to an agreement reached at the DOE Technical Exchange on Thermal Effects on Flow (TEF)/U.S. Nuclear Regulatory Commission (NRC), January 8–9, 2001. The text of the agreement (referred to as TEF 2.1) is the following.

"Consider measuring losses of mass and energy through the bulkhead of the drift-scale test (DST) and provide the technical basis for any decision or method decided upon (include the intended use of the results of the DST such as verifying assumptions in FEP exclusion arguments or providing support for TSPA models[)]. The DOE should analyze uncertainty in the fate of thermally mobilized water in the DST and evaluate the effect this uncertainty has on conclusions drawn from the DST results. The DOE's position is that measuring mass and energy losses through the bulkhead of the DST is not necessary for the intended use of the DST results. The DST results are intended for validation of models of thermally-driven coupled processes in the rock, and measurements are not directly incorporated into TSPA models. Results of the last two years of data support the validation of DST coupled-process models and the current treatment of mass and energy loss through the bulkhead. The DOE will provide the NRC a white paper on the technical basis for the DOE's understanding of heat and mass losses through the bulkhead and their effects by April 2001. This white paper will include the DOE's technical basis for its decision regarding measurements of heat and mass losses through the DST bulkhead. This white paper will address uncertainty in the fate of thermally mobilized water in the DST and also the effect this uncertainty has on conclusions drawn from the DST results. The NRC will provide comments on this white paper. The DOE will provide analyses of the effects of this uncertainty on the uses of the DST in response to NRC comments."[1]

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[1]Reamer, C.W. *U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Thermal Effects on Flow, January 8–9, 2001.* Letter (January 26) to S. Brocoum, U.S. Department of Energy. Washington, DC: U.S. Nuclear Regulatory Commission. 2001.

2 MEASURING MASS AND ENERGY LOSSES THROUGH THE BULKHEAD OF THE DRIFT-SCALE TEST

2.1 U.S. DEPARTMENT OF ENERGY TECHNICAL BASIS FOR THE DECISION NOT TO MEASURE HEAT AND MASS LOSSES FROM DRIFT-SCALE TEST

The DOE technical basis for the decision not to measure losses of mass and energy escaping from the DST through the thermal bulkhead can be summarized by the following five main points:

(1) "The main objective of the DST is to acquire a more in-depth understanding of the thermally driven coupled processes in the potential repository rocks...," and "[t]he DST results are intended for validation of models of thermally driven coupled processes in the rock ..."

(2) The mean error between measured temperatures at 1,700 thermal sensors and modeled temperatures is small. In addition, qualitative comparisons of the modeled extent of dryout and moisture redistribution with geophysical data are reasonably good.

(3) Actual measurements of losses through the DST bulkhead are difficult and include significant uncertainty.

(4) "The DOE's position is that the coupled processes are understood well enough to analyze this artifact [unmonitored heat and mass flow through the DST bulkhead] quantitatively [using the DST model]."

(5) "[D]irect measurement of the heat and mass loss through the bulkhead is not needed to satisfy the primary objective of the DST."

2.2 COMMENTS ON THE U.S. DEPARTMENT OF ENERGY TECHNICAL BASIS FOR NOT MEASURING HEAT AND MASS LOSSES FROM DRIFT-SCALE TEST

The arguments presented in the DOE white paper for justifying the decision not to measure mass and energy losses through the DST bulkhead have been extensively discussed by the DOE thermal testing team for the past several years. At the Tenth Thermal Workshop in Berkeley, California, on May 11, 2000, it was argued that thermohydrologic models matching measured temperatures were sufficient to account for losses through the bulkhead.[1] Other DOE scientists at the workshop countered that such an approach is circular reasoning. Their countering argument was that the test could not be used to validate the model if, at the same time, the model was being used to infer the unmonitored boundary condition imposed by the bulkhead on the test. The NRC agrees that simultaneously using the DST results to validate a model while using the model to infer the boundary condition at the bulkhead is problematic.

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[1]Hughson, D. and L. Browning. *Tenth Thermal Test Workshop, Livermore, California, May 11, 2000: Trip Report.* Memorandum (May 30) to U.S. Nuclear Regulatory Commission. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses. 2000.

The NRC has maintained that unmonitored mass and energy losses through the DST bulkhead increase the difficulty of interpreting the test results and decrease the utility of the test for validating thermohydrologic models (U.S. Nuclear Regulatory Commission, 2000). This position is partially substantiated by the evolution in the DOE understanding of the effects of bulkhead losses on the DST observations. The white paper states that dripping outside the bulkhead of the DST, observed beginning in the second month of heating, "was consistent with the heating of a large volume of rock that is highly fractured and approximately 90-percent saturated." But the observed dripping is also consistent with vapor escaping through the bulkhead and condensing in the cooler connecting drift. Thermohydrologic models were subsequently modified by DOE to allow for convection through the bulkhead. Preliminary measurements suggested 5 kW of conductive heat loss and from 2 to 20 kW of convective heat loss through the bulkhead (Civilian Radioactive Waste Management System Management and Operating Contractor, 1998). Later modeling studies found heat losses, peaking at 38 kW in the first year of heating then declining to 26 kW at 4 yr, were almost entirely from convection with only 1 kW of the loss occurring by conduction. These modeling studies, with the wingheater boreholes represented as high permeability conduits to facilitate the flow of vapor from the rock into the heated drift, resulted in a better match of modeled to measured temperatures. A DOE scientist at the Eleventh Thermal Workshop, October 5–6, 2000, reported on analyses suggesting that as much as two-thirds of the water heated to boiling in the DST escaped through the bulkhead.[2] The dripping in the connecting drift also provided an early indication of the effects of barometric pumping on the DST. More recent modeling sensitivity studies suggest that barometric pumping may increase convective heat loss through the bulkhead by as much as 42 percent (Civilian Radioactive Waste Management System Management and Operating Contractor, 2001). These efforts, and the summary provided in the white paper, illustrate the difficulties and uncertainties inherent in assessing the effect of losses through the bulkhead.

The difficulties and uncertainties in assessing the effect of losses through the bulkhead on DST results are recognized by DOE. Potential effects of losses through the bulkhead include reducing the volumes of heated rock and refluxing condensate and modifying thermohydrologic behavior in the near-field test environment. While the white paper claims that "a measurement of heat and mass losses through the bulkhead of the DST does not appear necessary," DOE scientists are developing plans to take a series of measurements in the connecting drift outside the bulkhead prior to initiating cooldown. At the Twelfth Thermal Test Workshop, R. Jones presented DOE plans to place relative humidity and temperature sensors in the connecting drift to monitor changes while ventilation is temporarily halted.[3] At the workshop, it was announced that the first measurement is planned for July 2001. The white paper presents only arguments against monitoring the bulkhead and concludes it is not necessary. There is no discussion in the white paper regarding the planned measurements or why they are being undertaken. The white paper summarizes arguments given by the DOE against monitoring losses through the bulkhead. This summary is a distillation of extensive discussions at thermal workshops and does not include arguments made by DOE scientists in favor of monitoring losses through the bulkhead at the DST.

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[2]Hughson, D. *Eleventh Thermal Test Workshop, Berkeley, California, October 5–6, 2000: Trip Report.* Memorandum (October 19) to U.S. Nuclear Regulatory Commission. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses. 2000.

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

3 USING DRIFT-SCALE TEST RESULTS TO SUPPORT PERFORMANCE ASSESSMENTS

3.1 UNCERTAINTY IN THE FATE OF THERMALLY MOBILIZED WATER IN THE DRIFT-SCALE TEST

A global energy balance of the DST, reported in the white paper, showed 77 percent of the energy input went into heating the rock, 12 percent into heating water, and 11 percent into boiling water. Of the water vaporized, approximately two-thirds escaped through the bulkhead and into the ventilation system while the remainder migrated into cooler regions of the rock and condensed. As stated in the white paper, "[i]f the DST were a totally closed system, then the zones of increased liquid saturation in the test block would contain possibly three times the volume of water." The phrase "uncertainty in the fate of thermally mobilized water," however, is slightly misleading. The uncertainty of concern is not so much where the water went, but instead, how thermohydrological processes would have differed had three times as much water condensed in the zones of increased saturation within the DST rather than escaping through the bulkhead.

Models of the DST capture thermohydrological behavior that is well represented by volume-averaging assumptions, such as heat transport by conduction and the spatial distribution of dryout zones. But the models use homogeneous property assumptions for networks of discrete fractures and, thus, are unable to capture thermohydrological behavior in large, highly permeable discrete fractures, such as those observed at approximately 12 m and 35–40 m from the bulkhead near the heated drift at the DST. While it should be fairly straightforward to analyze the volume-averaged thermohydrological behavior of the DST for a closed system simply by running the validated model with a closed boundary representing the bulkhead, it is not possible to predict the thermohydrological behavior in discrete fractures for a closed system since these features are not included in the models.

3.2 EFFECT OF UNCERTAINTY FROM BULKHEAD LOSSES ON DRIFT-SCALE TEST RESULTS

The white paper emphasizes that "measurements in the DST are not being applied directly to address performance issues." "For example," the white paper goes on to say, "the reduced volume of condensed water in the open-system (compared to that of an ideally closed system) can reduce the potential of seepage into the drift. Thus, it would not be appropriate to conclude that water will not seep into the potential emplacement drifts, because the DST remote camera has not shown water dripping into the Heated Drift." The white paper concludes that, "[i]f TH process models of anticipated repository conditions indicate seepage does not occur into the emplacement drifts, then the results are credible because the TH process models have been validated using DST measurements of thermal-hydrological responses." The white paper ends with the following caveat:

"Similarly, because of the smaller volume of condensed water in the open-system DST, the hydrological observations of possible fluid movement during the cool-down phase of the DST may differ from that of a closed system. Therefore, caution must be exercised not to directly apply the results of DST to performance issues."

The DOE reasoning is that, since there has been no dripping observed in the heated drift of the DST, and thermohydrological models validated against the DST show no seepage into the heated drift, seepage into emplacement drifts during the thermal period of the proposed repository is unlikely. This reasoning has at least two shortcomings. One shortcoming is that seepage into the heated drift of the DST may have been prevented by removal of two-thirds (as stated in the white paper) of the water from the condensation zone, and the other shortcoming is the thermohydrological models do not include a process that may lead to seepage into emplacement drifts during the thermal period. Experimental data collected near a high-permeability subvertical feature located at approximately 12 m from the bulkhead in the DST show preferential condensate drainage maintaining a temperature near boiling within the fracture while surrounding rock is dried out and temperatures are well above boiling. A mechanism by which liquid water could seep into emplacement drifts while temperatures within drifts are above boiling is by rivulets flowing preferentially in high-permeability subvertical fractures. Phillips (1996) showed that the distance water in a rivulet would remain in the liquid phase while surrounded by rock at above-boiling temperatures is proportional to the square root of the volumetric flow rate in the rivulet. Data from the DST indicate this process is occurring in several locations within the test block, such as at approximately 12 m and 35–40 m from the bulkhead (Civilian Radioactive Waste Management System Management and Operating Contractor, 2001), but this process is not incorporated into thermohydrological models that represent the fractures as a homogeneous continuum. Since losses through the bulkhead of the DST may be mitigating seepage into the heated drift and the thermohydrological models do not include the potentially important process of rivulet flow in discrete fractures, neither can be used as credible arguments that liquid water will not reach the engineered barriers in the emplacement drifts during the thermal period of the proposed repository.

4 PATH TOWARD RESOLUTION OF AGREEMENT TEF 2.1, MEASURING LOSSES OF MASS AND ENERGY THROUGH THE BULKHEAD OF THE DRIFT-SCALE TEST

Staff recommend DOE continue to pursue plans to measure losses of mass and energy through the bulkhead of the DST, as discussed at the Twelfth Thermal Workshop on June 8, 2001, and use these data in interpreting the test results.

Staff concerns remain that the full range of variability in thermohydrological processes and system states is not propagated from process models through model abstractions to performance assessments (U.S. Nuclear Regulatory Commission, 2000). For example, a comparison of several property sets against the DST data indicated the DST data are insufficient to allow discrimination between the different property sets (Civilian Radioactive Waste Management System Management and Operating Contractor, 2000). Because the thermal testing data cannot uniquely establish which property set is best, the range of model results produced by all the different property sets should be encompassed by the range of thermohydrologic conditions used for performance assessments. This concern is the subject of an agreement reached at the DOE/NRC technical exchange that says the DOE should "represent the full variability/uncertainty in … the abstraction of the thermodynamic variables." Losses of mass and energy through the bulkhead and the resulting saturation decrease in the condensation zones, however, may increase the uncertainty in using DST data to validate models and property sets for use in performance assessments. Therefore, as stated in agreement TEF 2.1, "[t]he DOE will provide analyses of the effects of this uncertainty [losses through the bulkhead] on the uses of the DST ..." in addition to analyses of other sources of model and data uncertainty.

The Cross-Drift Thermal Test (CDTT), planned to begin in fiscal year 2002, will provide an opportunity to test the DOE hypotheses that (i) thermally mobilized water will shed between emplacement drifts, (ii) there will be no penetration of the boiling isotherm by liquid water, and (iii) mobilized waters will have a chemistry benign to engineered barrier materials. The CDTT results may allay concerns regarding the unmonitored mass and energy losses through the bulkhead of the DST. To accomplish the goals of the CDTT, however, DOE should consider how heterogeneity in the fracture permeability affects condensate drainage through the boiling zone and the collection of water in the sampling boreholes. If data collected from the CDTT were to support the hypothesis that there will be no penetration of the boiling isotherm by liquid water, these data would need to be reconciled with evidence from the Large Block Test and the DST horizontal boreholes, which indicate penetration of the boiling isotherm by liquid water.

Heterogeneity in fracture network permeability and the presence of high-permeability subvertical fractures are not presently included in thermohydrological models of Yucca Mountain but will be considered in future studies as discussed and agreed to at the DOE/NRC Technical Exchange on Thermal Effects on Flow, January 8–9, 2001. Confidence in the ability of thermohydrolgic models to predict seepage into drifts during the repository thermal period would be significantly increased if these models represented the behavior of preferentially flowing rivulets in subvertical fractures. Part of this confidence building could be achieved by comparing numerical model results to theoretical analyses. As expressed in agreement TEF 2.8, "[t]he DOE will consider the NRC suggestion of comparing the numerical model results to the O.M. Phillips analytical solution documented in WRR (1996)."

5 CONCLUSION

The objective of the DST is to increase understanding of coupled thermohydrological processes in the fractured tuff of Yucca Mountain. These coupled thermohydrological processes involve thermal mobilization of matrix pore water, redistribution, condensation, and drainage through a complex network of fractures. Unfortunately, approximately two-thirds of the pore water thermally mobilized in the DST escaped from the test block through the bulkhead. Staff recognize that uncertainties exist in the data collected from the DST and that measurements of losses through the bulkhead may themselves be uncertain. However, staff are supportive of DOE plans to measure losses through the bulkhead in the fourth year of heating of the DST and believe they may help to resolve some concerns about the effects of these losses. Upon completion of agreement TEF 2.1 "[t]he DOE will provide analyses of the effects of this uncertainty [mass and energy losses through the bulkhead of the DST] on the uses of the DST in response to NRC comments."

6 REFERENCES

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