March 11, 2003

Joseph D. Ziegler, Acting Director
Office of License Application and Strategy
U.S. Department of Energy
Office of Repository Development
P.O. Box 364629 M/S 523
North Las Vegas, NV 89036-8629

SUBJECT: THERMAL EFFECTS ON FLOW AGREEMENT 2.01; STATUS: COMPLETE

Dear Mr. Ziegler:

In your letter dated December 24, 2002, the U.S. Department of Energy (DOE) transmitted information titled “Response to KTI Agreement Item Thermal Effects on Flow (TEF) 2.01" to close TEF 2.01. The U.S. Nuclear Regulatory Commission (NRC) staff has reviewed this information and has determined the status of TEF 2.01 to be “complete.”

TEF Agreement 2.01 has three components including: (i) DOE would consider measuring losses through the bulkhead and provide a white paper on the technical basis for DOE’s understanding of the losses and their effects on results; (ii) NRC would comment on the white paper; and (iii) DOE would provide analyses of the effects of uncertainty on uses of the Drift-Scale Heater Test (DST) data and conclusions that consider the NRC comments on the white paper.

As noted in your letter, DOE submitted a white paper titled “Heat and Mass Flow Through the Bulkhead in the Drift Scale Test” to the NRC on April 30, 2001. The NRC provided comments on the white paper on August 29, 2001. Therefore, the first two components of the agreement were completed previously.

Information transmitted in your letter of December 24, 2002, addresses the last component of TEF Agreement 2.01 (DOE would provide analyses of the effects of uncertainty on uses of the DST data and conclusions that consider the NRC comments on the white paper) and is the subject of the enclosed staff review. Previously, DOE responses to the NRC comments on the white paper were discussed in a teleconference on February 1, 2002.

In summary, NRC staff was concerned that heat and mass losses through the bulkhead might (i) mask preferential flow along fractures breaching the dryout zone and (ii) create additional data uncertainty should DST model-derived parameters be used in other seepage process models or abstractions for the performance assessment.

To address the concern that the DST model may not adequately represent preferential flow along a fracture, and thus potential finger-flow breaching of the boiling isotherm, DOE provided clarification that conclusions from DST modeling are not being used as a basis to preclude preferential flow through fractures. This clarification was provided in a February 6, 2003, teleconference. In that teleconference, DOE indicated that a model with a refined grid and including heterogeneity would be documented in a revision to CRWMS M&O (2000). This refined model was being developed to support the representation of seepage in the thermohydrologic models while also addressing the O.M. Phillip analytical solution for preferential flow along a fracture breaching the dryout zone (this will be addressed in the future under TEF Agreement 2.08). Furthermore, the DOE report on TEF Agreement 2.01 restated that the effect of heterogeneity on condensate drainage and heat and mass losses through the bulkhead both need to be addressed in the design of the Cross-Drift Thermal Test.

To address the concern of NRC staff on data uncertainty caused by using DST model-derived parameters, DOE provided clarification in the February 6, 2003, teleconference that data were derived independently of the DST (i.e., Technical Database Management System). The NRC staff notes that evaluation of parameter (and model) uncertainty will also be addressed in the future under TEF Agreement 2.10.

The NRC will monitor the use of DST data and conclusions in other models, such as in the revision of CRWMS M&O (2000) that describes the thermal seepage model. In addition, staff will monitor the evaluation and propagation of uncertainty in thermohydrological models that will be addressed under TEF Agreements 2.08 and 2.10. The NRC believes TEF Agreement 2.01 does not need to remain open to track the usage of data and conclusions derived from the DST, therefore, it is listed as "Complete." If you have any questions regarding this matter, please contact Mr. Bill Dam of my staff at (301) 415-6710 or by e-mail at wld@nrc.gov.

Sincerely,

/RA/

Janet R. Schlueter, Chief
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: NRC Review of DOE Document
Pertaining to Thermal Effects on
Flow Key Issue Agreement 2.01

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Sincerely,
/RA/

Janet R. Schlueter, Chief
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: NRC Review of DOE Document Pertaining to Thermal Effects on Flow Key Issue Agreement 2.01

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NRC Review of DOE Document Pertaining to
Thermal Effects on Flow Key Technical Issue Agreement 2.01

The U.S. Nuclear Regulatory Commission (NRC) goal of issue resolution during this interim pre-licensing period is to assure that the U.S. Department of Energy (DOE) has assembled enough information on a given issue for NRC to accept a license application for review. Resolution by the NRC staff during pre-licensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. Just as important, resolution by the NRC staff during pre-licensing does not prejudge what the NRC staff evaluation of that issue will be after its licensing review. Issues are resolved by the NRC staff during pre-licensing when the staff has no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments on a previously resolved issue.

This enclosure addresses Thermal Effects on Flow (TEF) Agreement 2.01, which was reached between NRC and DOE during a technical exchange and management meeting.[1] This agreement pertains to uncertainty in thermohydrological models caused by heat and mass losses through the bulkhead during the Drift-Scale Heater Test (DST).

Thermal Effects on Flow Agreement 2.01

Wording of the Agreement: TEF Agreement 2.01 states “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 Features, Events, and Process (FEP) exclusion arguments or providing support for Total System Performance Assessment (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 on the results 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.”

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[1]Reamer, C.W. “U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Unsaturated and Saturated Flow Under Isothermal Conditions (January 8–9, 2001).” Letter (January, 2001) to S. Brocoum, DOE.

NRC Review

Background: One of the open items previously identified to resolve TEF subissue 2 (thermal effects on temperature, humidity, saturation, and flux) is for DOE "to consider measuring losses of mass and energy through the bulkhead of the DST (NRC, 2000)." Observations of heat and mass losses through the bulkhead during the DST led to many discussions between DOE and NRC staff that eventually culminated in the TEF 2.01 Agreement. There are three components to the TEF 2.01 Agreement: (i) DOE would consider measuring losses through the bulkhead and provide a white paper on the technical basis for DOE's understanding of the losses and their effects on results; (ii) NRC would comment on the white paper; and (iii), DOE would provide analyses of the effects of uncertainty on uses of the DST data and conclusions that consider the NRC comments on the DOE white paper.

Part way through the 4-year heating phase of the field test, the DOE considered and attempted a number of different methods for monitoring the heat and mass losses through the bulkhead. Difficulties in monitoring the heat and mass losses, combined with DOE's confidence in the thermohydologic model of the DST, led to DOE's current approach of using model estimates for quantifying the heat and mass loss through the bulkhead. The justification for not measuring heat and mass losses through the bulkhead and instead using model estimates was documented in the first of the three components for the TEF 2.01 Agreement. This first component was a DOE white paper titled "Heat and Mass Flow Through the Bulkhead in the Drift Scale Test" that was enclosed in a DOE letter to NRC;[2] herein, that enclosure will be referred to as the DOE white paper. The DOE technical basis for the decision not to measure losses of heat and mass escaping from the DST through the thermal bulkhead can be summarized by the following five main points taken from the DOE white paper.

1. "The main objective of the [Drift-Scale Heater Test] is to acquire a more in-depth understanding of the thermally driven coupled processes in the potential repository rocks...", and "the [Drift-Scale Heater Test] 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 measurements are reasonably good.

3. Actual measurements of losses through the Drift-Scale Heater Test 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 [Drift-Scale Heater Test] bulkhead) quantitatively (using the [Drift-Scale Heater Test] model)."

5. "Direct measurement of the heat and mass loss through the bulkhead is not needed to satisfy the primary objective of the [Drift-Scale Heater Test]."

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[2]Brocoum, S.J. "Transmittal of Reports and Data Addressing Key Technical Issue (KTI) Exchanges. (January 8–9, 2001)." Letter (April 30, 2001) to C.W. Reamer, NRC.

The second component of TEF Agreement 2.01 requiring documentation was the NRC's comments on the DOE white paper. The NRC comments were contained in a letter[3] to DOE titled "Thermal Effects on Flow Agreements." The NRC response discussed: (i) evaluating and propagating the full range of model and parameter uncertainty derived from the DST through to performance assessment; (ii) addressing heterogeneity and preferential flow into models, while noting the O.M. Phillips analytical solution (Phillips, 1996) for preferential flow along a fracture breaching the dryout zone; and (iii) planning for the Cross-Drift Thermal Test that addresses heterogeneity and the problem of heat and mass loss out a bulkhead.

The third component of TEF Agreement 2.01, to consider the effect of uncertainty on the uses of the DST data, was discussed in two NRC and DOE teleconference calls and is the subject of the report reviewed here. The DOE outlined their responses to the NRC comments to the DOE white paper during a teleconference on February 1, 2002. These responses were documented by DOE in a letter[4] and accompanying technical report, herein referred to as the DOE report on TEF 2.01. In another teleconference call, on February 6, 2003, the DOE clarified uses of the DST data and conclusions for supporting other thermohydrological and performance assessment models. This third component of TEF Agreement 2.01 agreement is the subject of the following NRC staff review.

DOE's Report: The DOE report on TEF Agreement 2.01, submitted on December 24, 2002, provides both a response to the NRC comments and an evaluation of uncertainties of heat and mass losses through the bulkhead using the DST model (Sections 3.1 and 3.2 of the DOE report, respectively). DOE concluded they consider TEF Agreement 2.01 to be fully addressed and recommended that, upon the NRC review and acceptance of this submittal, the agreement be considered closed.

In Section 3.1 of the DOE report on TEF Agreement 2.01, DOE responses are given for 10 points extracted from the NRC comments on the DOE white paper. Noteworthy among the responses are that DOE indicated that: (i) studies to compare numerical simulations to the O.M. Phillips analytical solution (Phillips, 1996) will be addressed under the TEF Agreement 2.08; (ii) evaluation and propagation of model and parameter uncertainty in thermohydrologic models will be addressed under the TEF Agreement 2.10; (iii) important components of thermohydrologic behavior are considered sufficiently understood, thus this model can be applied to repository conditions; (iv) models are not considered validated based on observations of no dripping; (v) models will have to take into account discrete fracture effects in the vicinity of the drifts and fracture heterogeneity; and (vi) the effect of heterogeneity and condensate drainage through the boiling zone needs to be considered in the design of the Cross-Drift Thermal Test.

In Section 3.2 of the DOE report on TEF Agreement 2.01, a short summary is given of a model uncertainty study that is intended to be published as a journal article (Mukhopadhyay and Tsang, in preparation). A draft of the journal article was not available for this review.

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[3]Reamer, C.W. "Thermal Effects on Flow Agreements." Letter (August 29, 2001) to S.J. Brocoum, DOE.

[4]Brocoum, S.J. "Transmittal of Report and Data Addressing Key Technical Issue (KTI) Agreement Item Thermal Effects on Flow (TEF) 2.01." Letter (December 24, 2002) to J.R. Schlueter, NRC. Enclosed report: Tsang, Y., R. Wagner, and M. Zhu, "Response to KTI Agreement Item TEF 2.01" MISCRW–HS–000001 REV 01. December 2002.

Two alternative conceptualizations were analyzed, the first with vapor transport pathways only through the natural fractures and the second with the additional vapor transport pathway through the wing-heater boreholes, which were modeled as high-permeability conduits. The second conceptualization appears to be the improved model that added “realism to the model” (first conceptualization) as discussed in Section 3.1 of the DOE report on TEF Agreement 2.01. The DOE report on TEF Agreement 2.01 included a number of conclusions from the modeling of the two conceptualizations. One, average temperature differences between the models and measured data were reported to be less than 1°C [1.8 °F] for the first two years of the heating phase of the experiment. Two, model estimated changes in fracture permeability caused by changes in fracture saturation agreed with measured values of air permeability. No mention is made, however, of the effect of thermal-mechanical changes to the fracture network on fracture permeability. Three, average changes to fracture saturations were less than 20 percent for 90 percent of the model domain. With a hypothetical closed boundary for the bulkhead, the fracture saturations were said to only increase by 20 percent. DOE noted that the techniques for measuring saturation in fractures are qualitative and cannot distinguish the estimated changes in saturation. Details of the model uncertainty study would be needed for a thorough review, however, a detailed review was unnecessary at this time for two reasons. One, evaluation of model and parameter uncertainty would be addressed in TEF Agreement 2.10 according to the DOE report on TEF Agreement 2.01. Two, in the NRC\DOE teleconference call on February 6, 2003, DOE provided clarification that model parameter values and conclusions from the DST would not be used as a basis for parameter values or assumptions by other thermohydrologic or performance assessment models.

<u>Staff Comments on the Use of DST Data and Conclusions</u>: An overarching NRC concern is that data derived from modeling or that conclusions on preferential flow of water in fractures from the DST would be used in other process models or in performance assessment models. Because of the unknown heat and mass losses through the bulkhead, NRC is concerned that hydrologic parameter values may not reflect behavior of the repository and that preferential flow of water along fractures is not included in thermohydrological models.

To understand this NRC concern, it is noted that the DST modeling is primarily constrained by temperature measurements (i.e., water conditions are predominantly qualitatively known). To obtain an estimate of the heat and mass losses through the bulkhead, model input parameter values and the boundary condition at the bulkhead had to be assumed known. The estimate of losses through the bulkhead was derived from a global energy balance of the DST model. As reported in the DOE white paper, 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 DOE white paper, “[i]f the [Drift-Scale Heater Test] 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.” NRC is concerned that monitored conditions reflecting fluid flow during the test may have differed markedly had three times as much water condensed in the zones of increased saturation within the DST rather than escaping through the bulkhead. Conditions that were muted because the water escaped through the bulkhead possibly would have been enhanced had the water remained in the test domain. These postulated differences in monitored conditions may have led to the identification of different values for hydrologic parameters.

Because the thermohydrologic parameter values (e.g., fracture permeability, fracture van Genuchten parameters, and matrix-fracture interaction exponent) and bulkhead boundary conditions were considered known when estimating heat and mass losses through the bulkhead, NRC was concerned that other models might use parameter values derived from or supported by the DST results. It has not always been clear to NRC how parameters from the DST were used in other models (e.g., thermal seepage model). Were the parameters in other models based on the DST modeling results (i.e., derived or modified)? Observations, model results, and conclusions can be used directly (e.g., to validate concepts or provide a supporting basis for parameter values) and indirectly (e.g., infer that a modeling grid is adequately designed). Furthermore, DOE is currently revising analysis model reports for a license application, thus, NRC is not able to determine how DST observations, modeling results, and conclusions are being used. DOE addressed this concern in the teleconference call of February 6, 2003, when DOE clarified that the DST model uses thermohydrologic parameter values taken from the Technical Database Management System. DOE also provided clarification that support for those parameter values was derived from other parts of the Yucca Mountain program.

Also during the teleconference call of February 6, 2003, evolution of parameter values in the Yucca Mountain Program over the time period of the DST, and the possible impact the DST modeling had on that evolution was discussed. Fracture porosity is an example of a parameter that has evolved during the period of the DST. NRC has been using DOE data sets in thermohydrologic analyses and had noted that intrinsic fracture permeability had a profound effect on results. By definition, intrinsic fracture permeability is the bulk fracture permeability divided by the fracture porosity. Values for fracture porosity of middle nonlithophysal unit were set to about 10^{-4} at the time when the test began. Values for fracture porosity are currently set to about 10^{-2}. This difference in fracture porosity has a profound effect on whether a heat pipe is predicted by the thermohydrologic model. The presence (or absence) of a heat pipe can have a marked effect on heat and mass transfer, including the possible occurrence of penetration of the boiling isotherm by water flowing down a fracture. During the teleconference call of February 6, 2003, DOE stated that there was other project evidence to support the change in fracture porosity values and that the DST model results would not be cited as a supporting basis for that change.

<u>Staff Comments on Preferential Flow Breaching the Boiling Isotherm:</u> NRC was concerned that losses through the bulkhead of the DST may be mitigating seepage into the heated drift. Furthermore, thermohydrological models may not have been constructed to include the potentially important process of preferential flow along fractures, and thus should not be used as credible support that liquid water will not reach the engineered barriers in the emplacement drifts during the above boiling period of the proposed repository.

The basis for NRC’s concern is that 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 [39 ft and 115–131 ft] from the bulkhead near the heated drift at the DST. Experimental data collected near a high-permeability subvertical feature located at approximately 12 m [39 ft] 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 may be occurring in several locations within the test block, such as at the approximately 12 m and 35–40 m [39 ft and 115–131 ft] locations from the bulkhead, but this process is not incorporated into thermohydrological models that represent the fractures as a homogeneous continuum.

In the DOE report on TEF Agreement 2.01, the DOE states that a better representation of seepage processes will be used to assess the possibility of preferential flow in fractures. In response to the NRC concern that hydrological processes would be substantially different if moisture was not allowed to escape through the bulkhead, the DOE report on TEF Agreement 2.01 answered that "[Bechtel SAIC Company, LLC] judges that the same essential processes would be present, although quantitative differences would exist in the magnitudes and extents of those processes occurring in the rock of the [Drift-Scale Heater Test]." More importantly, DOE stated "if this TH model when applied to specific repository conditions, taking account of discrete fracture effects in close vicinity of the drift, predicts no seepage, then the prediction can be considered credible ...."

Because the revisions to the thermal seepage and TSPA models for a license application are not yet released to NRC, staff was concerned DOE might not address preferential flow along fractures breaching the dryout zone. Use of appropriate grid size, incorporation of heterogeneity in continuum models, or discrete fracture models would be needed to represent preferential flow along a fracture. Adequate grid resolution is important when representing preferential flow along fractures in a continuum model. Based on changes in seepage results in numerical analyses by Pruess (1997), an adequate grid resolution was not being used in the DST model that would allow its results to be used in performance assessment. In addition, the DST model uses homogeneous properties for the middle nonlithophysal unit taken from the Technical Database Management System, which were derived from calibrations of the three-dimensional site-scale unsaturated flow model. Intralayer heterogeneity needs to be considered to represent preferential flow. Liu, et al. (2002) overlaid a stochastically-generated fracture network on their fracture continuum grid to construct a possible pattern of intralayer heterogeneity. The discrete features generated in the continuum model by discrete fracture pattern led to markedly increased values of seepage, as compared to those heterogeneous or homogenous models where capillary barrier effects led to the seepage threshold concept.

In the NRC and DOE teleconference call of February 6, 2003, DOE clarified that the DST observations or modeling results would not be cited as support for assumptions or conclusions that preferential flow along fractures is not expected to breach the dryout zone surrounding the drifts. Not citing the DST for support refers to assumptions and conceptualizations used for other process models or the performance assessment models. Also during the teleconference call, DOE noted that a separate model was developed to address the topic of preferential flow along fractures. This model, using a finely-resolved grid and heterogeneous properties, would be documented in the next revision of CRWMS M&O (2000).

<u>Summary of Staff Comments:</u> The last component of TEF Agreement 2.01 to complete was "the DOE will provide analyses of the effects of this uncertainty on the uses of the [Drift-Scale

Heater Test] in response to NRC comments."   NRC staff was concerned that heat and mass losses through the bulkhead might (i) mask preferential flow along fractures breaching the dryout zone and (ii) create additional data uncertainty should DST model-derived parameters be used in other seepage process models or abstractions for the performance assessment.

To address the concern that the DST model may not adequately represent preferential flow along a fracture, and thus potential finger-flow breaching of the boiling isotherm, the DOE provided clarification in the February 6, 2003, teleconference that conclusions from DST modeling are not being used as a basis to preclude preferential flow through fractures. DOE also indicated that a model with a refined grid and heterogeneity would be documented in a revision to CRWMS M&O (2000). This refined model was being developed to support the representation of seepage in the thermohydrologic models while also addressing the O.M. Phillip analytical solution for preferential flow along a fracture breaching the dryout zone (will be addressed in the future under TEF Agreement 2.08). Furthermore, the DOE report on TEF Agreement 2.01 restated that the effect of heterogeneity on condensate drainage and heat and mass losses through the bulkhead both need to be addressed in the design of the Cross-Drift Thermal Test.

To address the concern of NRC staff on data uncertainty caused by using DST model-derived parameters, the DOE provided clarification in the February 6, 2003, teleconference that data were derived independently of the DST (i.e., Technical Database Management System). The staff notes that evaluation of parameter (and model) uncertainty will be addressed in the future under TEF Agreement 2.10.

The NRC will monitor the use of DST data and conclusions in other models, such as in the revision of CRWMS M&O (2000) that describes the thermal seepage model. In addition, staff will monitor the evaluation and propagation of uncertainty in thermohydrological models addressed in TEF Agreements 2.08 and 2.10. The NRC believes this agreement does not need to remain open to track the usage of data and conclusions derived from the DST, therefore, it is listed as "Complete."

Additional Information Needed

None.

Status of Agreement

TEF Agreement 2.01 is considered complete.

References

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