THE U.S. NUCLEAR REGULATORY COMMISSION OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY'S KEY TECHNICAL ISSUE AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA: THERMAL EFFECTS ON FLOW 2.04, 2.05, 2.07 AND GENERAL 1.01, COMMENTS 5 AND 16

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this interim pre-licensing period is to ensure the U.S. Department of Energy (DOE) has assembled enough information about a given issue for NRC to accept a license application for review. It is important to note that resolution of an issue by NRC during the pre-licensing period does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are resolved by the NRC staff during pre-licensing when the NRC staff have no further questions or comments about how DOE is addressing the issue. Pertinent new information could raise new questions or comments about a previously resolved issue.

By letter dated November 25, 2003, DOE submitted a report, Technical Basis Document No. 5: In-Drift Chemical Environment, Appendix L (Bechtel SAIC Company, LLC, 2004a), that contains DOE's responses to Agreement Thermal Effects on Flow (TEF).2.04.

By letter dated August 20, 2004, DOE submitted a report, Technical Basis Document No. 5: In-Drift Chemical Environment, Appendix M (Bechtel SAIC Company, LLC, 2004a), that contains DOE's responses to Agreements TEF.2.05, GEN.1.01 (Comments 5 and 16).

By letter dated April 28, 2004, DOE submitted the Ventilation Model and Analysis Report (Bechtel SAIC Company, LLC, 2004b) that contains DOE's response to Agreement TEF.2.07.

Other agreements and comments addressed in the three DOE technical basis documents are not addressed here. For all preceding agreements and comments, DOE stated it had satisfied the NRC information needs regarding the agreements, and all agreements should be considered complete.

This document is organized with separate sections for each agreement or group of agreements. Each section includes an introduction, a discussion of the relevance to repository performance, and the NRC evaluation and any comments. A summary and status of all agreements reviewed in this document are included in Summary and Status of Agreements.

2.0 REVIEW OF TECHNICAL BASIS DOCUMENT NO. 5: IN-DRIFT CHEMICAL ENVIRONMENT, APPENDIX L: MULTISCALE THERMAL-HYDROLOGIC MODEL (RESPONSE TO TEF.2.04) AND APPENDIX M: COLD-TRAP EFFECTS [RESPONSE TO AGREEMENTS TEF.2.05 AND GEN.1.01 (COMMENTS 5 AND 16)]

The DOE responses to Agreements TEF.2.04, 2.05, and GEN.1.01 (Comments 5 and 16) are provided in Appendixes L and M of Bechtel SAIC Company, LLC (2004a). Agreements TEF.2.04 and 2.05 were reached at a meeting held January 8–9, 2001, to discuss the TEF KTI (Reamer, 2001a). Agreement GEN.1.01 (Comments 5 and 16) was reached at a meeting held

September 18–19, 2001, to discuss the range of thermal operating temperatures (Reamer, 2001b).

The wordings of each agreement is as follows:

TEF.2.04

“Provide the Multi-Scale Thermohydrologic Model AMR, Rev. 01. The DOE will provide the Multi-Scale Thermohydrologic Model AMR (ANL–EBS–MD–00049) Rev. 01 to the NRC. Expected availability is FY 02.”

TEF.2.05

“Represent the cold-trap effect in the appropriate models or provide the technical basis for exclusion of it in the various scale models (mountain, drift, etc.) considering effects on TEF and other abstraction/models (chemistry). See page 11 of the Open Item (OI) 2 presentation. The DOE will represent the cold-trap effect in the Multi-Scale Thermohydrologic Model AMR (ANL–EBS–MD–00049) Rev. 01, expected to be available in FY 02. This report will provide technical support for inclusion or exclusion of the cold-trap effect in the various scale models. The analysis will consider thermal effects on flow and the in-drift geochemical environment abstraction.”

GEN.1.01 (Comment 5)

“DOE did not adequately assess the probability and effects of condensation forming under the drip shield for the LTOM.”

GEN.1.01 (Comment 16)

“Closed drifts will have RH [Relative Humidity] close to 1.0. Small temperature gradients in this environment may result in convection, vapor transport, and dripping from condensation. This provides a pathway for water to enter the drift, by vapor exchange at the drift wall, and drip onto engineered materials. Presently the DOE considers convection and condensation in a drift cross-section but does not consider convection along the drift axis. Basis: Detailed discussions of the bases for Agreements TEF.2.04 and TEF.2.05 are provided in NRC (2000). Agreement TEF 2.05 addresses condensation generally under the heading of cold-trap effect. This agreement specifically addresses lateral flow of vapor along the drift axis in response to temperature gradients such as those created by the edge-effect. This process may be responsible for the dripping observed in the sealed ECRB [Enhanced Characterization of Repository Block] drift.”

2.1 Relevance to Repository Performance

The NRC is concerned that predictions of temperature and amount of moisture reaching the drip shield, waste package, and invert might be poorly estimated if the in-drift processes of natural convection and condensation are neglected (NRC, 2000). At the meeting summarized in Reamer (2001a), no basis was presented for neglecting natural convection and the cold-trap process in DOE’s total system performance assessment (TSPA). Moisture conditions observed in DOE’s Passive Test of the Enhanced Characterization of Repository Block drift indicate the possibility of significant moisture redistribution in closed drifts caused by convection and condensation.

Agreements TEF.2.04 and 2.05 have been categorized by NRC as having medium risk significance (Travers, 2003). Individual comments within GEN.1.01 have not been separately categorized within the risk significance framework (Travers, 2003).

2.2 NRC Evaluation and Comment

The DOE summarizes results from two modeling efforts in Appendix M of Bechtel SAIC Company, LLC (2004a) that address the concern of natural convection and condensation. The two modeling efforts are computational fluid dynamics modeling of gas-phase flow in drifts and thermohydrological porous media modeling of the combined host rock and in-drift areas. The DOE considers two scales in Bechtel SAIC Company, LLC (2004a), drift scale and repository scale. Drift-scale effects include those associated with heterogeneous heat loads from neighboring waste packages (e.g., waste package to waste package temperature differences and waste package to drip shield and invert temperature differences). Repository scale effects address concerns with axial natural convection caused by repository edge cooling.

Based on the modeling results, DOE includes cold-trap effects between the drip shield and drift wall in performance assessment models, including the rewetting of the invert, either directly or indirectly, by condensed water. The DOE concludes those processes of condensation on the underside of the drip shield could be neglected because it is considered a low-probability event. The DOE also concludes that condensation on drift walls when the drift wall temperature is above 96 EC [205 EF] could be neglected.

The computational fluid dynamics modeling focuses on drift-scale effects. Dispersion coefficients are developed for the drift-scale environment with different values for the air gaps below and above the drip shield. The DOE states, in Appendix M of Bechtel SAIC Company, LLC (2004a), that repository-scale moisture redistribution by convection can be neglected because the drifts will be open at the ends, and condensation will occur in cool areas beyond the last waste package. In addition, DOE concludes that condensation also will occur in the cooler area of the waste package standoff zone near the exhaust shaft in the center of drifts. To determine whether DOE's conclusions (based on results of its computational fluid dynamics modeling) are appropriate, the NRC staff will need to ensure details of the underground facility design, as presented in the potential license application, have been appropriately included in the computational fluid dynamics models. Examples of design elements that could affect computational fluid dynamics model results include standoff from exhaust shafts and bulkheads near the ends of emplacement drifts. These design elements have been considered in other topical areas of review.

The thermohydrological porous media model (Bechtel SAIC Company, LLC, 2004c) simulates in-drift moisture redistribution caused by repository-scale convection cells along drifts using binary diffusion coefficients. A leaky bulkhead at the end of an emplaced waste package drift was assumed for one set of simulations using the porous media model. Alternatively, an open drift (no bulkhead) was assumed for another set of simulations. As expected, the open drift led to additional heat and mass transfer away from the emplaced waste packages. Thus, the approach for the porous media model using a leaky bulkhead in Bechtel SAIC Company, LLC (2004c) is preferred by DOE when a basis for neglecting natural convection and condensation processes is being established.

In the thermohydrological porous media model, the use of binary diffusion coefficients and the neglect of buoyancy are simplifications that need supporting bases. The use of binary diffusion coefficients for moisture redistribution may be reasonable if there is a supporting basis for the values of the dispersion coefficients. The DOE, however, provides no supporting basis for dispersion coefficients that include the effect of axial convection associated with repository edge cooling (Bechtel SAIC Company, LLC, 2004c). In addition, the amount of in-drift heat transfer along a drift represented by simplifying the three-dimensional natural convection flow patterns as linear heat transfer along the drift in the thermohydrological porous media model is not supported. In the summary provided by DOE (Bechtel SAIC Company, LLC, 2004a), the amount of heat and mass transferred axially along the drift at the repository scale, as estimated by the thermohydrological porous media model, was not supported by measured data or comparison with computational fluid dynamics modeling of repository-scale, in-drift gas-phase flow.

During the potential license application review, NRC may examine, as appropriate, information about model validation for the computational fluid dynamics and thermohydrological porous media models. Measured data from laboratory experiments, field tests, or relevant literature data would add confidence to the results of the modeling exercises. Data from the Passive Test of the Enhanced Characterization of Repository Block drift have been mentioned by DOE as relevant for supporting natural convection and cold-trap models.

The documents cited in Bechtel SAIC Company, LLC (2004a) for detailed information about these modeling efforts have not yet been released by DOE. Staff notes that Revision 01 of the multiscale thermohydrological model (Bechtel SAIC Company, LLC, 2004c) contains a description of a three-dimensional thermohydrological porous media model that appears similar to the one summarized in Bechtel SAIC Company, LLC (2004a). Revision 02 of the multiscale thermohydrological model (Bechtel SAIC Company, LLC, 2004d) is cited in the summary description provided in Bechtel SAIC Company, LLC (2004a); however, this revision is not yet publicly available.

In summary, DOE provided information responsive to the concerns underlying Agreements TEF.2.04, 2.05, and GEN.1.01 (Comments 5 and 16). Information was provided about general effects of natural convection and the cold-trap process for Agreement TEF.2.05. The DOE noted a detailed description would be contained in the yet-to-be-released Bechtel SAIC Company, LLC (2003). Also, to address Agreement GEN.1.01 (Comment 5), DOE provided a rationale for the conclusion that substantial waste package degradation would not occur during the period when evaporation and condensation would occur. As part of the general information about natural convection and condensation, DOE provided information about axial, repository-scale effects which addresses Agreement GEN.1.01 (Comment 16). The DOE should consider the technical comments provided above.

3.0 REVIEW OF THE VENTILATION MODEL AND ANALYSIS REPORT (BECHTEL SAIC COMPANY, LLC, 2004b) FOR AGREEMENT TEF.2.07

Bechtel SAIC Company, LLC (2004b) provides DOE’s response to Agreement TEF.2.07.

Agreement TEF.2.07 was reached during the NRC/DOE Technical Exchange and Management Meeting on Thermal Effects on Flow held January 8–9, 2001 (Reamer, 2001a). The wording of this agreement is as follows:

<u>TEF.2.07</u>

"Provide the Ventilation Model AMR, Rev. 01 and the Pre-Test Predictions for Ventilation Test Calculation, Rev. 00. The DOE will provide the Ventilation Model AMR (ANL–EBS–MD–000030), Rev. 01 to the NRC in March 2001. Note that ventilation test data will not be incorporated in the AMR until FY02. The DOE will provide Pre-test Predictions for Ventilation Tests (CAL–EBS–MD–000013), Rev. 00 to the NRC in February 2001. Test results will be provided in an update to the Ventilation Model AMR (ANL–EBS–MD–000030) in FY 02."

There are three components to Agreement TEF.2.07. The first component of Agreement TEF.2.07, "provide Pre-test Predictions for Ventilation Tests," was considered complete by Schlueter (2001). The second component of Agreement TEF.2.07, provide the "Ventilation Model AMR (ANL–EBS–MD–000030), Rev. 01," was considered complete by Schlueter (2002). The third component of Agreement TEF.2.07, provided in Ziegler (2004), and reviewed herein, was to "update the Ventilation Model AMR" using the data collected in laboratory-scale ventilation tests to validate the ventilation model. Whereas DOE stated (Ziegler, 2004) that responses for Agreements TEF.2.07 and Repository Design and Thermal-Mechanical Effects (RDTME).3.14 were provided in Bechtel SAIC Company, LLC (2004b), only the response for Agreement TEF.2.07 is reviewed here.

Agreement TEF.2.07 focuses on the ability of the pre-closure forced ventilation system to remove heat, specifically, as it affects initial conditions for the post-closure period. The related agreement, RDTME.3.14, focuses on the pre-closure effects of ventilation.

3.1 Relevance to Repository Performance

Heat removal by ventilation is an important aspect of a potential repository design. Ventilation also leads to moisture removal from the drift walls, which may affect heat transfer, corrosion of engineered components during the pre-closure period, and initial conditions for the post-closure period. The NRC described concerns (NRC, 2000; Schlueter, 2001, 2002) with the supporting basis for results from DOE's ventilation model, which was derived using the ANSYS software. The two types of support identified for DOE's ANSYS ventilation model were measured data from DOE laboratory experiments and detailed process-level modeling that did not require the simplifications made for the ANSYS ventilation model.

Agreement TEF.2.07 has been categorized by NRC as having low risk significance (Travers, 2003).

3.2 NRC Evaluation and Comment

The DOE calculates time-dependent heat load reduction factors to represent the effect of forced ventilation. The detailed analytical approach and measured data from the Atlas Facility ventilation test were used to support heat removal estimates calculated using the ANSYS ventilation model. Based on the NRC experience in developing a ventilation model, staff stated aggregated heat load reduction factors greater than 0.70 would require a more detailed basis than previously provided (Schlueter, 2002). Heat load reduction factors up to 0.90 are used by DOE's thermohydrological, thermal-chemical-hydrological, and thermal-mechanical models (hereafter collectively referred to as downstream thermal models). To support the larger heat load reduction factors estimated by the ANSYS ventilation model, DOE replaced the detailed process-level model MULTIFLUX with a detailed analytical analysis (Ziegler, 2004; Bechtel SAIC Company, LLC, 2004b). The DOE also presented data from the Atlas Facility ventilation test and provided a discussion about the limitations of the measured data in supporting the ANSYS ventilation model (Bechtel SAIC Company, LLC, 2004b). The NRC found DOE to be responsive to the concerns expressed in the agreements based on the information provided.

Based on the NRC evaluation of the information provided by DOE, there are additional areas identified by NRC that DOE should consider. These are summarized in the following:

- Differences in direction of heat transfer between the Kuehn and Goldstein (1978, 1976) and the Atlas Facility ventilation models make it difficult to compare data from the two experiments; hence, it is difficult to assess the heat transfer model implemented in the ANSYS ventilation model for surfaces in the emplacement drifts.

- For the uncertainty analysis, include consideration of:

    — Validity of the assumption of linear system response for the Delta Method;

    — Basis for the range selected for important input parameters; and

    — Magnitude of the temperature metric {± 5 EC [± 9 EF]} used for matching Atlas Facility ventilation test data compared with the temperature difference {2 EC [3.6 EF]} that would account for the discrepancy in heat mass balance for the test.

- Appropriateness of a uniform ventilation heat load reduction factor of 0.90 by downstream users when Bechtel SAIC Company, LLC (2004b) only supports a factor 0.86 for typical drifts.

The NRC recognizes that documentation of downstream thermal models is being revised and is not yet publicly available. Review of new information presented in the potential license application may raise additional questions.

4.0 SUMMARY AND STATUS OF AGREEMENTS

The NRC reviewed the KTI agreement responses provided by DOE in Bechtel SAIC Company, LLC (2004a–b) to determine if sufficient information was provided to complete the agreement items. The NRC believes DOE was responsive to the NRC concerns identified in the agreements. On the basis of this review and notwithstanding new information that could raise new questions or comments, DOE has provided sufficient information for NRC to consider Agreements TEF.2.04, 2.05, 2.07 and GEN.1.01, Comments 5 and 16, closed.

DOE should consider additional technical comments that were identified and are summarized in the following paragraphs. Also, because some DOE documents are not yet publicly available, NRC noted further questions may arise at the time a potential license application is reviewed.

Agreements TEF.2.04, 2.05, and GEN.1.01 (Comments 5 and 16)

The NRC found DOE to be responsive to the concerns raised in the agreements. The DOE presented a summary of approaches and results for evaluating the effects of natural convection and the cold-trap process. Details of the modeling are to be documented in Bechtel SAIC Company, LLC (2003), which is a new analysis and model report not yet publicly available. The DOE should consider: (i) ensuring consistency between repository designs used to support computational fluid dynamics modeling and those designs that would be included in a potential license application; (ii) providing a supporting basis for the estimates of the magnitude of heat and mass transfer along drifts (Bechtel SAIC Company, LLC, 2004c); and (iii) providing a supporting basis for the estimates of binary diffusion coefficients used for in-drift cells of the repository scale thermohydrological porous media model (Bechtel SAIC Company, LLC, 2004c).

Agreement TEF.2.07

The NRC found DOE to be responsive to the concerns raised in the agreement. Description of a detailed analytical approach and use of the Atlas Facility ventilation test data were provided as support for the ANSYS ventilation model calculations in Bechtel SAIC Company, LLC (2004b). Limitations of the experimental setup resulted in measured data that were inconsistent with the ANSYS ventilation model for axial heat transfer and for heat transfer coefficients at the analog drift wall surface. The DOE uncertainty analysis, which was based on the ANSYS ventilation model, should include clarification of the linear assumption, input bases, and the relationship to the Atlas Facility ventilation test.

5.0 REFERENCES

Bechtel SAIC Company, LLC. "Technical Basis Document No. 5: In-Drift Chemical Environment." Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004a.

———. "Ventilation Model and Analysis Report." ANL–EBS–HS–000030. Rev. 03 ICN 03, Errata 2. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004b.

———. "Multiscale Thermohydrologic Model." ANL–EBS–MD–000049. Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004c.

———. "Multiscale Thermohydrologic Model." ANL–EBS–MD–000049. Rev. 02B. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004d.

———. "In-Drift Natural Convection and Condensation Model." MDL–EBS–MD–000001. Rev. 00A. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003.

Kuehn, T.H. and R.J. Goldstein. "An Experimental Study of Natural Convection Heat Transfer in Concentric and Eccentric Horizontal Cylindrical Annuli." *Journal of Heat Transfer*. Vol. 100, No. 4. pp. 635–640. 1978.

———. “Correlating Equations for Natural Convection Heat Transfer Between Horizontal Circular Cylinders.” *International Journal of Heat and Mass Transfer*. Vol. 19, No. 10. pp. 1,127–1,134. 1976.

NRC. “Issue Resolution Status Report, Key Technical Issue: Thermal Effects on Flow.” Rev. 3. Washington, DC: NRC. 2000.

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, DOE. ML010290382. Washington, DC: NRC. 2001a. <www.nrc.gov/waste/hlw-disposal/public-involvement/mtg-archive.html#KTI>

———. “U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Range of Operating Temperatures (September 18–19, 2001).” Letter (October 2) to S. Brocoum, DOE. ML012820043. Washington, DC: NRC. 2001b. <www.nrc.gov/waste/hlw-disposal/public-involvement/mtg-archive.html#KTI>

Schlueter, J.R. “Thermal Effects on Flow Agreement 2.07.” Letter (July 3) to J.D. Ziegler, DOE. Washington, DC: NRC. 2002. <www.nrc.gov/reading-rm/adams.html>

———. “Thermal Effects on Flow Agreement 2.07.” Letter (August 29) to J.D. Ziegler, DOE. Washington, DC: NRC. 2001. <www.nrc.gov/reading-rm/adams.html>

Travers, W.D. “Final Staff Response to March 19, 2003, Requirements Memorandum on the Waste Arena Briefing—M030303A.” Letter (June 5) to Chairman Diaz and Commissioners Dicus, McGaffigan, and Merrifield. Washington, DC: NRC. 2003. <www.nrc.gov/reading-rm/adams.html>

Ziegler, J.D. “Transmittal of Key Technical Issue (KTI) Agreements Thermal Effects on Flow (TEF) 2.07 and Repository Design and Thermal-Mechanical Effects (RDTME) 3.14.” Letter (April 08) to NRC, Document Control Desk of High-Level Waste Branch. Las Vegas, Nevada: DOE, Office of Civilian Radioactive Waste Management. 2004. <www.nrc.gov/reading-rm/adams.html>