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: STRUCTURAL DEFORMATION AND SEISMICITY 3.01 ADDITIONAL INFORMATION NEEDED, RADIONUCLIDE TRANSPORT 3.05, AND UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS 6.03

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 docket a License Application (LA) 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. Also, and just as important, resolution of an issue by the NRC staff during pre-licensing does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are considered resolved by the NRC staff during pre-licensing when the staff have no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments about a previously resolved issue.

By a letter dated July 28, 2004, DOE submitted a report, Appendix H of Technical Basis Document No. 3: Water Seeping into Drifts (Bechtel SAIC Company, LLC, 2003a). The DOE responses to three NRC key technical issue (KTI) agreements are contained in this appendix.

This report contains a staff review of DOE's responses to Agreements Structural Deformation and Seismicity (SDS) 3.01 Additional Information Needed (AIN)–1, Radionuclide Transport (RT) 3.05, and Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 6.03.

2.0 WORDINGS OF AGREEMENTS SDS.3.01 AIN–1, RT.3.05, and USFIC.6.03

Agreement SDS.3.01

Agreement SDS.3.01 was reached at a meeting held October 11–12, 2000, to discuss the SDS KTI (Schlueter, 2000). The wording of this agreement follows:

"The Enhanced Characterization of the Repository Block (ECRB) long-term test and the Alcove 8–Niche 3 test need to be "fracture-informed" (i.e., observation of seepage needs to be related to observed fracture patterns). Provide documentation which discusses this aspect. DOE responded that for the passive test, any observed seepage will be related to full periphery maps and other fracture data in testing documentation. The documentation will be available by any potential License Application (LA). For Niche 3, fracture characterization is completed and a 3-D representation will be included in testing documentation. The documentation will be available August, 2001."

Agreement SDS.3.01 AIN–1

The DOE previously responded to Agreement SDS.3.01 (Brocoum, 2001). After reviewing this response, NRC identified an additional information need, referred to as SDS.3.01 AIN–1 (Schlueter, 2002). The wording of SDS.3.01 AIN–1 follows:

"The NRC staff requests the documentation to show how, or the methodology to ensure that, actual or expected hydrologic and transport test results were or will be interpreted in light of fracture-fault patterns and lithostratigraphic information in the test volume vicinity."

Agreement RT.3.05

Agreement RT.3.05 was reached at a meeting held December 5–7, 2000, to discuss the RT KTI (Reamer, 2000a). The wording of this agreement follows:

"Provide the documentation for the Alcove 8–Niche 3 testing and predictive modeling for the unsaturated zone. DOE will provide documentation for the Alcove 8–Niche 3 testing and predictive modeling for the unsaturated zone in updates to the AMRs In Situ Field Testing of Processes and Radionuclide Transport Models Under Ambient Conditions, both available to the NRC in FY 2002."

Agreement USFIC.6.03.

Agreement USFIC.6.03 was reached at a meeting held October 31–November 2, 2000, to discuss the USFIC KTI (Reamer, 2000b). The wording of this agreement follows:

"The DOE will complete the Alcove 8 testing, taking into consideration the NRC staff comments, if any, and document the results in a DOE-approved AMR, due date: May 2001."

3.0 RELEVANCE TO REPOSITORY PERFORMANCE

Agreement SDS.3.01 AIN–1 requests DOE to demonstrate that hydrologic and transport test results (i.e., infiltration and seepage) from Alcove 8–Niche 3 are interpreted in terms of the fracture-fault patterns (as documented in the full-periphery geologic mapping) and other fracture data and lithostratigraphic information. The information requested of DOE is important because it demonstrates consistency between the infiltration/seepage observations and the abstraction of these processes for performance assessment in the potential License Application. Quantitative descriptions of fracture characteristics at the test locations and interpretation of test results in terms of these characteristics could support technical bases of the DOE fracture-continuum approach to drift-scale seepage modeling. This information also is potentially important for performance confirmation activities if repository construction begins and if performance confirmation is to include seepage processes based on potentially available fracture data collected during tunnel boring activities.

Agreement RT.3.05 requests a description of the results of field testing in Alcove 8–Niche 3 and a comparison of the test results to pretest model predictions of tracer transport. The Alcove 8–Niche 3 tests provide an opportunity to test the conceptual model of matrix diffusion in the unsaturated zone at an intermediate scale relevant to the potential repository. The tests also provide a means to build confidence in radionuclide transport modeling approaches that

use the active-fracture concept for flow and transport in the unsaturated zone. Other tests, such as those at Busted Butte and Alcove 1, have not been conducted in densely welded units of the Topopah Spring Tuff. The DOE sensitivity analyses suggest that matrix diffusion processes in the unsaturated Topopah Spring Tuff provide significant waste isolation capabilities (Bechtel SAIC Company, LLC, 2004).

Agreement USFIC.6.03 requests completion of field testing in Alcove 8–Niche 3 to demonstrate the conceptual model of matrix diffusion in the unsaturated zone. Matrix diffusion is a process by which solutes dissolved in water flowing in a fracture diffuse into relatively stagnant water within the pore space of the rock matrix. Within the rock matrix, there is substantially greater mineral surface area available for sorption of radionuclides. Matrix diffusion can thus provide significant storage capacity for sorbing radionuclides and, if effective in the unsaturated zone, result in significant delay of radionuclide transport to the saturated zone.

4.0 NRC EVALUATION AND COMMENT

Agreement SDS.3.01 AIN–1

The DOE characterization of fractures in the Alcove 8–Niche 3 tests was limited to mapping fractures with trace lengths greater than 1 m [3.28 ft]. During unsaturated conditions, however, it is often the smallest interconnected fractures with the narrowest apertures that control flow patterns, capillary diversion, and seepage because these are the fractures with the highest capillary strength. Under fully saturated conditions, the more readily observable fractures are more likely to play a role in conducting flow. The differences in hydrologic properties between the larger, more observable fractures and the smallest, difficult-to-observe fractures are a possible explanation for the observations in Alcove 8–Niche 3 tests. Infiltration under ponded conditions showed a moderate to weak positive correlation to observable fracture density, while seepage rates under unsaturated conditions showed no clear correlation to fracture density. Although detailed studies of microfractures (i.e., fractures visible with the aid of a microscope) at scales relevant to making inferences about drift seepage throughout the potential repository would be time consuming, such studies are standard methodology in structural geology (e.g., Dezayes, et al., 2000; Ortega and Marrett, 2000; Laubach, et al., 2002; Wilson, et al., 2003). Further, DOE staff collected data about small-scale fractures {i.e., trace lengths less than 1 m [3.28 ft]} in the Enhanced Characterization of the Repository Block (DTN: GS990908314224.009), and these data could have been used to better fracture-inform the infiltration and seepage results for the Alcove 8–Niche 3 tests.

Although DOE staff made some efforts toward fracture-informing the infiltration and seepage results of the Alcove 8–Niche 3 large-plot test, they did not conduct these analyses for the fault test. DOE should explain what was learned about the hydrologic characteristics of the fault under the conditions of the fault test, or the effects of the fault on the infiltration and seepage results, or demonstrate that the fault had little or no impact on the test results. As such, NRC considers DOE’s response to SDS.3.01 AIN–1 to be insufficient for completion of the agreement at this time.

Agreement RT.3.05

Appendix H of Bechtel SAIC Company, LLC (2003a) does not provide a discussion of results for the tracer testing conducted at Alcove 8–Niche 3, nor does it provide information or

interpretation of results compared to pretest predictive modeling. Some results of tracer tests of the fault and small block are presented in Bechtel SAIC Company, LLC (2003b) and Liu, et al. (2004). As noted in the evaluation of USFIC.6.03, the limited test results available indicate matrix diffusion is an important process affecting transport of the tracers used in the Alcove 8–Niche 3 tests. Results appear consistent with the expected behavior of the tracers used in the tests. The DOE indicated the Alcove 8–Niche 3 tests do not directly support the development or abstraction of unsaturated zone process models for performance assessment (Bechtel SAIC Company, LLC, 2003a, Appendix E). Results of tracer testing for the large-plot test can provide important insight into: (i) the processes affecting radionuclide transport in the unsaturated zone; and (ii) the capabilities of current transport models to adequately capture these processes. Until DOE publishes the results of the remaining tracer tests and comparison of results to the pretest predictions, the staff considers Agreement RT.3.05 as incomplete.

Although not explicitly directed toward transport modeling, the information provided in Appendix D of Bechtel SAIC Company, LLC (2003a) to address Comment 2 (Section 5.0) appears sufficient and staff has no further questions prior to receipt of the LA on the model approach as it may be applied to unsaturated transport in a potential LA.

Agreement USFIC.6.03

Agreement USFIC.6.03 requests completion of field testing in Alcove 8–Niche 3 to test the conceptual model of matrix diffusion in the unsaturated zone. The DOE conceptual model of matrix diffusion in the unsaturated zone is supported by laboratory and field tests. Laboratory data from diffusion-cell, rock-beaker, and fractured-core experiments (CRWMS M&O, 2001) are used to estimate effective matrix diffusion coefficients for the unsaturated zone transport model. The conceptual model of matrix diffusion in the unsaturated zone is justified by *in-situ* field testing that includes an analysis of tracer transport from the Alcove 1 infiltration experiments that suggests tracer breakthrough data are fit best by a numerical model that includes the effects of matrix diffusion (Bechtel SAIC Company, LLC, 2003b). However, the Alcove 1 transport experiments were not conducted in the same host-rock formation as the potential repository. The DOE, therefore, agreed to present the results of tracer transport studies in Alcove 8–Niche 3, which were aimed at providing additional evidence for matrix diffusion in the Topopah Springs upper lithophysal and middle nonlithophysal units. The DOE response to Agreement USFIC.6.03 summarizes results of the Alcove 8–Niche 3 tracer studies, which are addressed more thoroughly by Bechtel SAIC Company, LLC (2003b).

During the first phase of Alcove 8–Niche 3 testing, water was introduced along a fault zone under ponded conditions on the floor of Alcove 8 until quasi-steady-state seepage was observed in Niche 3107 (Niche 3). Then, a finite volume of water containing two tracers with different molecular diffusion coefficients was introduced into the fault. Results of the first phase of the tracer transport test show clearly that the tracer with the lower matrix diffusion coefficient (pentafluorobenzoicacid) reached an earlier and higher peak concentration than the tracer with the higher matrix diffusion coefficient (bromide) (Bechtel SAIC Company, LLC, 2003b, Figure 6.12.2-8). Because both these nonsorbing tracers were applied simultaneously, the difference in tracer arrival times is best explained by the conceptual model in which the two solutes diffuse from fractures into the rock matrix at different rates. These tracer test results confirm the earlier results from the Alcove 1 experiments and provide sufficient justification for inclusion of the matrix diffusion process in DOE's unsaturated zone transport model for Yucca Mountain.

On the basis of this review and notwithstanding new information that could raise new questions or comments, DOE has provided sufficient information and staff has no further questions prior to receipt of the LA on matrix diffusion as a process in the unsaturated zone model.

Agreement Comments

Agreements SDS.3.01 AIN–1, RT.3.05, and USFIC.6.03 also request DOE to consider staff comments related to the Alcove 8–Niche 3 tests that emanated from our review of Agreements RT.3.06 and SDS.3.02 (Schlueter, 2003). The NRC staff provided eight specific comments as part of their review of Agreements RT.3.06 and SDS.3.02 (Schlueter, 2003). These comments, DOE's responses, and the NRC evaluations are summarized briefly next.

Comment 1 requests a complete description of tests conducted in Alcove 8–Niche 3 and identification of the tests to which the pretest predictions apply. The DOE response provides a description of test conditions and observations for the large-plot test, and a reference to the Analysis Model Report (Bechtel SAIC Company, LLC, 2003b) that contains documentation of the experimental conditions and results from the fault test in Alcove 8–Niche 3. The DOE response also indicates the referenced pretest predictions apply to the fault test. The test descriptions provided by DOE for the tests conducted to date addresses the staff's comments and staff considers Comment 1 to be addressed.

Comment 2 requests justification for the use of an active-fracture continuum model to simulate the Alcove 8–Niche 3 tests. The DOE response refers to information in Appendix D of the technical basis document (Bechtel SAIC Company, LLC, 2003a), which provides a summary of analyses to demonstrate the continuum approach appropriately captures in-fracture-plane flow diversion around drift openings. This response by DOE mainly provides justification for the continuum approach for seepage modeling, whereas the NRC comment was directed toward sufficient information necessary to develop a technical basis of both the active-fracture concept and the continuum approach for radionuclide transport modeling. Staff note, however, that DOE specifically addresses the basis for including the active-fracture concept in radionuclide transport modeling in responses to Agreements TSPAI.3.28 and 3.29, which are being reviewed separately. Staff, therefore, considers Comment 2 to be sufficiently addressed for purposes of completing Agreement USFIC.6.03.

Comment 3 requests an explanation of the applicability of test results if a mass balance of water cannot be determined. The DOE response explains that water mass lost to evaporation during Alcove 8–Niche 3 tests is small, and the mass of infiltrated water must be: (i) stored within the fractured rock between Alcove 8–Niche 3; (ii) diverted around the niche and flowed out of the system; or (iii) seeped into the niche. The response also refers to Appendix C of the technical basis document (Bechtel SAIC Company, LLC, 2003a), which indicates it is not feasible to obtain a mass balance of water for the Alcove 8–Niche 3 tests. Additionally, DOE indicates that results from the Alcove 8–Niche 3 seepage and transport tests are not directly incorporated into performance assessment abstractions, and support for the matrix diffusion conceptual model can be achieved without a full accounting for mass balance. It does not appear feasible to establish the fate of all infiltrated water and solute in these seepage and tracer tests, and it is, therefore, not possible to directly obtain quantitative parameter estimates for use in larger scale transport models. Notwithstanding this limitation, the test results described in DOE's response provide qualitative support for conceptual models such as matrix

diffusion and the capillary diversion of water around drift openings. Staff, therefore, considers Comment 3 to be addressed.

Comment 4 requests a basis for using the rock property values in pretest predictions. The DOE response explains that drift-scale rock properties were used as initial estimates for calibrating the numerical model for the fault test because these rock properties represent the best estimates of mean values for the drift scale, which is closer to the test-site scale than the 0.3-m [1-ft] scale used for measuring air permeabilities. Those initial estimates of rock properties were then modified by calibration to match observed seepage rates. Those calibrated rock properties then were used for the pretest transport predictions. This basis for selection of rock properties is sufficiently transparent in DOE's response, and staff considers Comment 4 to be addressed.

Comment 5 requests an explanation of the representativeness of tests when nearly saturated conditions have existed prior to tracer injection. The DOE response explains that previously saturated fractures had little effect on estimating the fracture–matrix interface area. The fracture–matrix interface area was evaluated by tracer tests in both the fault and large-plot tests. Infiltration rates during the tracer testing portion of the fault test were relatively stable and, thus, no sharp changes in fracture saturation were likely to have occurred. The DOE response indicates that they do not necessarily consider the conditions of the Alcove 8-Niche 3 tests to be representative of conditions simulated in the larger-scale seepage and transport models for performance assessment. Rather, these tests are used mainly to provide qualitative conceptual support (see preceding summary for Comment 3). Staff, therefore, considers Comment 5 to be addressed.

Comment 6 requests clarification of assumptions related to mass transfer from matrix to fractures versus fractures to matrix. The DOE response explains that different fracture–matrix interface-area reduction factors are used to calculate flow and transport processes for the different flow directions. During a wetting time period, flow direction is from fractures to the matrix, and the fracture–matrix interface area reduction factor is used. During the drying time, water flows from the matrix to fractures, and no reduction for the interface-area is used. The conceptual basis and assumptions used for transport modeling of the Alcove 8-Niche 3 tests are sufficiently explained in DOE's response, and staff considers Comment 6 to be addressed.

Comment 7 requests clarification whether the fracture–matrix system is in a state of disequilibrium during individual tests because of the rapidity of the sequence of tests. The DOE response explains that, to avoid the potential effects of disequilibrium or test interference, tracers were introduced after flow processes were stabilized, as evidenced by stable infiltration and seepage rates for each phase of the tests. This explanation is sufficient, given the qualitative nature in which the test results are used, and staff considers Comment 7 to be addressed.

Comment 8 requests descriptions of all features, events, and processes observed in the Alcove 8–Niche 3 tests. The DOE response and the Analysis Model Report for *in-situ* testing (Bechtel SAIC Company, LLC, 2003b) provide detailed descriptions of experimental initial and boundary conditions, observed fracture patterns, a discussion of the relation of seepage and infiltration rates with observed fracture patterns, and the results and interpretations of tracer transport tests. As discussed in the staff evaluation of Agreement RT.3.05 herein, DOE's

response does not provide a discussion of results for the tracer testing conducted at Alcove 8–Niche 3, nor does it provide information or interpretation of results compared to pretest predictive modeling. The additional descriptions of test results needed to address Agreement RT.3.05 would serve to address this comment.

5.0 SUMMARY

The NRC staff evaluated the DOE responses to three KTI agreements. These agreement responses are contained in Appendix H to Bechtel SAIC Company, LLC (2003a). The specific agreements evaluated were SDS.3.01 AIN–1, RT.3.05, and USFIC.6.03.

The NRC staff conclude that the information provided by DOE to address Agreement SDS.3.01 AIN–1 is not responsive to the original staff concerns. The NRC staff conclude that the information provided by DOE to address Agreement RT.3.05 does not address the original staff concerns. The NRC staff conclude that the information provided by DOE to address agreement USFIC.6.03 is responsive to the original staff concerns. The NRC staff conclude that seven of the eight specific comments evaluated in Section 5 of this review contain information that addresses the original staff concerns, while the response to Comment 8 was found not to address the original staff concern.

6.0 STATUS OF THE AGREEMENTS

Based on the preceding NRC staff review, NRC staff considers that DOE should provide additional information for SDS.3.01 AIN–1 and RT.3.05. It is for DOE to decide how, or whether, to respond to staff feedback. Based on the preceding staff review, NRC staff has no further questions at this time with respect to Agreement USFIC.6.03 and it is closed. Note that NRC will make its final determination regarding any issues relevant to licensing during review of the LA.

7.0 REFERENCES

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