April 13, 2004

Joseph D. Ziegler, Acting Director
Office of License Application and Strategy
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
1551 Hillshire Drive
North Las Vegas, NV 89134-6321

SUBJECT: PRE-LICENSING EVALUATION OF UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS KEY TECHNICAL ISSUE AGREEMENT 4.06 [STATUS: COMPLETE], RADIONUCLIDE TRANSPORT KEY TECHNICAL ISSUE AGREEMENT 3.06 [STATUS: COMPLETE], AND STRUCTURAL DEFORMATION AND SEISMICITY KEY TECHNICAL ISSUE AGREEMENT 3.02 [STATUS: COMPLETE]

Dear Mr. Ziegler:

In a letter dated October 31, 2003, the U.S. Department of Energy (DOE) submitted a report titled, “Technical Basis Document No. 3 (TBD No. 3): Water Seeping Into Drifts,” which contains DOE’s responses to seven agreements reached between DOE and the U.S. Nuclear Regulatory Commission (NRC) and pertaining to the following key technical issues: Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC), Total System Performance Assessment and Integration, Radionuclide Transport (RT), Structural Deformation and Seismicity (SDS), and Thermal Effects on Flow. The staff review of DOE’s responses to three of the seven agreements is based on information requests by NRC that are documented in the summary highlights of three DOE and NRC technical exchange and management meetings. This report provides a summary of NRC staff evaluation of these three agreements: USFIC.4.06, RT.3.06, and SDS.3.02. The staff evaluation of the remaining DOE responses to key technical issue (KTI) agreements addressed by TBD No. 3 will be provided separately.

NRC reviewed DOE’s KTI agreement responses within the report to determine whether any aspect of the agreements were excluded from the response. No omissions were found. On the basis of this review, NRC agrees with DOE that the information assembled in response to the agreements is acceptable to support the submission of a license application for the proposed repository at Yucca Mountain, Nevada. Notwithstanding new information that could raise new questions or comments concerning the above agreements, NRC considers the information provided satisfies the intent of the Agreements USFIC.4.06, RT.3.06, and SDS.3.02, and that these agreements are complete.

If you have any questions regarding this matter, please contact Daniel Rom, of my staff at (301) 415-6704 or by e-mail to DSR@nrc.gov.

Sincerely,

C. William Reamer, Director
Division of High Level Waste Repository Safety
Office of Nuclear Material Safety
and Safeguards

Enclosure:
NRC Review of DOE Agreement Responses

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If you have any questions regarding this matter, please contact Dan Rom, of my staff at (301) 415-6704 or by e-mail to DSR@nrc.gov.

Sincerely,

/RA/

C. William Reamer, Director
Division of High Level Waste Repository Safety
Office of Nuclear Material Safety
and Safeguards2

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Letter or Memorandum to J. Ziegler from C. Reamer, dated: April 13, 2004
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REVIEW BY THE OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS OF THE U.S. DEPARTMENT OF ENERGY AGREEMENT RESPONSES RELATED TO THE PROPOSED GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA: “UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS” (USFIC) KEY TECHNICAL ISSUE (KTI) AGREEMENT 4.06, “RADIONUCLIDE TRANSPORT” (RT) KTI AGREEMENT 3.06, AND “STRUCTURAL DEFORMATION AND SEISMICITY” (SDS) KTI AGREEMENT 3.02 [PROJECT NO. WM–00011]

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this interim prelicensing period is to assure that the U.S. Department of Energy (DOE) has assembled enough information about a given issue for NRC to accept a license application for review. Resolution by the NRC staff during prelicensing 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 NRC during prelicensing does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are resolved by the NRC staff during prelicensing 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 about a previously resolved issue.

By letter dated October 31, 2003, DOE submitted a report titled, “Technical Basis Document No. 3 (TBD No. 3): Water Seeping Into Drifts” (Bechtel SAIC Company, LLC, 2003a), which contains DOE responses to the information requests of seven DOE and NRC agreements pertaining to the following key technical issues (KTI): Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC), Total System Performance Assessment and Integration (TSPAI), Radionuclide Transport (RT), Structural Deformation and Seismicity (SDS), and Thermal Effects on Flow (TEF).

This report provides a summary of the NRC staff evaluation of three of the seven DOE responses to KTI agreements covered in TBD No. 3 (Bechtel SAIC Company, LLC, 2003a). The staff evaluation of the remaining DOE responses to KTI agreements addressed by TBD No. 3 will be provided separately.

2.0 WORDING OF THE AGREEMENTS

The staff review of the DOE response to the three agreements evaluated in this report is based on information requests by NRC that are documented in the summary highlights of three DOE and NRC technical exchange and management meetings. Agreement SDS.3.02 was reached during a meeting held October 11–12, 2000, to discuss the SDS KTI (Schlueter, 2000). Agreement RT.3.06 was reached during a meeting held December 5–7, 2000, to discuss the RT KTI (Reamer, 2000). Agreement USFIC.4.06 was reached during a meeting held August 6–10, 2001, to discuss the TSPAI KTI (Reamer, 2001). The wordings of these agreements are as follows.

USFIC.4.06: “Provide documentation of the results obtained from the Comparison of Continuum and Discrete Fracture Network Models modeling study. Alternatively, provide justification of the continuum approach at the scale of the seepage model grid (formerly June 20 letter, item xiii). DOE will provide documentation of the results obtained from the Comparison of Continuum and Discrete Fracture Network Models modeling study or provide justification of the continuum approach at the scale of the seepage model grid. This will be documented in Seepage Calibration Model and Seepage Testing Data Analysis Modeling Report (MDL–NBS–HS–000004) or other suitable document expected to be available to NRC in FY 2003."

RT.3.06: "The NRC needs DOE to document the pre-test predictions for the Alcove 8-Niche 3 work. DOE responded that pre-test predictions for Alcove 8-Niche 3 work will be provided to NRC via letter report (Brocoum to Greeves) by mid-January 2001."

SDS.3.02: "The NRC needs DOE to document the pre-test predictions for the Alcove 8-Niche 3 work. DOE responded that pre-test predictions for Alcove 8-Niche 3 work will be provided to NRC via letter report (Brocoum to Greeves) by mid-January 2001."

Note that Agreements RT.3.06 and SDS.3.02 have identical wording.

3.0 TECHNICAL INFORMATION PROVIDED IN THE DOE AGREEMENT RESPONSE

3.1 Agreement USFIC.4.06

The DOE response to Agreement USFIC.4.06 is provided in Appendix D of Bechtel SAIC Company, LLC (2003a). This response provides information to support the use of equivalent-continuum numerical grids to model drift seepage and comparisons of results from continuum and discrete-fracture network modeling studies.

The DOE response begins by acknowledging the complexity of phenomena that affect seepage into drifts on a wide range of spatial and temporal scales (e.g., small-scale roughness, fracture heterogeneity, film flow, drop formation and detachment, evaporation, and in-drift moisture redistribution). DOE states it is infeasible to develop a process model capable of simultaneously including all relevant processes because necessary characterization data are not available and computational demands would be prohibitive. The DOE response concludes that the seepage model basically serves as a transfer function that provides average seepage rates for a range of hydrogeologic conditions. This transfer function is stated to be based on physical principles and site data.

The numerical seepage model used to reproduce seepage-rate data from liquid release tests is conceptualized as a three-dimensional, heterogeneous fracture continuum that employs the Richards equation for flow in variably saturated porous continua and the van Genuchten-Mualem constitutive relationships for capillary pressure and relative permeability as functions of water saturation. Seepage rate measurements from 22 liquid release tests were used to calibrate the model and to estimate relevant parameters. The DOE response provides selected examples of seepage release tests showing that calculated and observed seepage rates respond similarly as a result of relative humidity fluctuations during transient liquid release tests. The effects of evaporation potential and ventilation are stated to be appropriately captured by the model. Only a single parameter, representing effective capillary strength, was adjusted to match the seepage-rate data.

After the model calibration process, the heterogeneous continuum modeling approach was tested for its capability to predict seepage for conditions different than those matched during the calibration effort. The DOE response provides only one example of a case in which seepage rates for a liquid-release test in Niche 3 were predicted with the calibrated model and compared to measured data. The case presented shows the model provides a generally good match to measured seepage rate data from Niche 3.

The DOE response acknowledges flow in fractures is limited to the fracture plane, and, thus, a three-dimensional heterogeneous fracture continuum conceptualization is appropriate for conditions of multiple connected fractures with variable orientations that can allow diversion of water around drift openings. Documentation of detailed line surveys indicates fracture frequencies observed in the potential repository host horizons range from 3.2 to 4.3 fractures per meter [1 m = 3.281 ft] and occur predominantly in three orientations, thus resulting in well-connected networks. It is stated that microcracks not counted in the detailed line surveys would also act to enhance fracture connectivity.

As additional support for the continuum modeling approach, the DOE response cites a peer-reviewed study by Jackson, et al. (2000) that concluded appropriately estimated effective continuum parameters are able to sufficiently represent underlying fracture network permeability. It should be noted, however, that the Jackson, et al. (2000) study considered only saturated permeability and may not be applicable for unsaturated flow in fracture networks where capillary retention in individual fractures can be a dominating factor.

The DOE response also provides a comparison between continuum and discrete-fracture network models. The accompanying discussion begins by noting that, while they are often considered conceptually and visually appealing alternatives to continuum models, discrete-fracture models still require numerous assumptions and simplifications. Aspects that must be accounted for in a defensible discrete-fracture network model include phase occupancy in fracture segments, fracture accessibility, entrapment of wetting and nonwetting phases, flow along and across fracture intersections, and flow channeling in fracture planes.

The DOE response cites a study by Finsterle (2000) that compared seepage predictions calculated with an effective fracture continuum model to those obtained with a discrete-fracture model. In this study, a two-dimensional, discrete-fracture model was used to generate a synthetic data set that was used as a calibration target for a two-dimensional continuum model. Additional data sets for differing seepage conditions were also generated with the discrete-fracture model for confirmatory comparisons to the results of the continuum model. The DOE response concludes the two modeling approaches yield consistent predictions of seepage threshold and rates if calibrated against late-time data from liquid-release tests. The response also notes the formulation of a two-dimensional, discrete-fracture model implicitly assumes fractures to be oriented parallel to the drift axis. Because flow in fractures is largely confined to the fracture plane, fractures oriented parallel to the drift would limit the amount of in-plane diversion that could occur around drifts. The response notes that, even during this extreme condition, the calibrated continuum model yields seepage predictions reasonably consistent with the discrete-fracture model. The continuum model was calibrated by adjusting the capillary strength parameter to a value much less than the corresponding parameter in the discrete-fracture approach.

The DOE response also summarizes a seepage modeling study by Liu, et al. (2002) that used a two-dimensional, discrete-fracture model. Unlike the model of Finsterle (2000), the Liu, et al. (2002) model did not show significant flow diversion around the modeled drift opening. The difference in results between the Liu, et al. (2002) and Finsterle (2000) models is attributed to the respective capillary strength parameter choices. Liu, et al. (2002) concluded that fracture network models need to be three-dimensional to realistically evaluate capillary barrier effects in fractured formations.

The DOE response emphasizes that alternative conceptual models, such as discrete-fracture network models, require detailed, currently unavailable characterization data. Additionally, these alternative models are based on additional model assumptions that are difficult to justify and, thus, require calibration against seepage data, in a manner similar to the calibration step for the continuum approach. The DOE response concludes by noting that flow equations solved in both discrete-fracture and fracture-continuum models are essentially identical, the only fundamental difference being the finer level of discretization of computational elements needed for the discrete-fracture approach. Staff comments about the DOE response to Agreement USFIC.4.06 are provided in Section 4.1 of this review.

3.2 Agreements RT.3.06 and SDS.3.02

DOE originally provided information pertinent to Agreements RT.3.06 and SDS.3.02 by letter report (Brocoum, 2001). Staff review of that report resulted in a number of comments and a request for specific additional information (Reamer, 2002). DOE provided a response by letter report (Ziegler, 2002) in which DOE noted that one additional information need, the pretest predictions for Phase II (unsaturated flow and transport) of the Alcove 8-Niche 3 testing, was not yet available. Subsequent NRC staff review of the letter report acknowledged the additional information need remained and reiterated several comments (Schlueter, 2003a).

The DOE response to Agreements RT.3.06 and SDS.3.02 and the request for additional information are provided in Appendix E (Bechtel SAIC Company, LLC, 2003a). This response contains information that directly addresses the requested additional information for Agreements RT.3.06 and SDS.3.02 and acknowledges that comments in Schlueter (2003a) are to be addressed in responses to other related agreements (i.e., RT.3.05, SDS.3.01, and USFIC.6.03). The underlying staff concern for these agreements was that DOE should demonstrate the predictive ability of their unsaturated flow and transport approach by providing pretest predictions for the Alcove 8-Niche 3 transport studies.

The DOE response provides a brief description of the construction, design, and remaining testing for the Alcove 8-Niche 3 tests. The response also provides new test predictions for the final part of the Phase I (saturated flow and transport) flow tests in the large-plot experiment, new test predictions for the Phase I tracer test in the large-plot experiment, and Phase II flow and tracer test predictions for the large-plot experiment. Although previously provided test plans (Brocoum, 2001) included Phase II flow and tracer testing for the fault test (also known as the modified small-plot test), these plans have since been abandoned. The DOE response indicates that testing at the large plot is expected to better characterize the flow and transport in the fracture network associated with Alcove 8-Niche 3.

The response provides a clear description of current test plans for Phase I tracer testing and Phase II flow and tracer testing in the large-plot experiment. Flow in the large plot was reduced in March 2003 to focus on the two (of twelve) plots with the highest net infiltration rate. After seepage responses provide information regarding connectivity of flow paths, flow will be restored to all plots. After a period to establish steady-state infiltration and seepage conditions, tracers will be added to initiate Phase I tracer testing. Upon completion of Phase I tracer testing, new lower flow steady-state conditions will be established for Phase II followed by Phase II tracer testing. Tables in Appendix E of the DOE response (Bechtel SAIC Company, LLC, 2003a) provide information about the type and use of tracers and estimated duration for each test.

As described in previous reports, a multiple interacting continua model, implemented through the codes iTOUGH2 V4.0 (Lawrence Berkeley National Laboratory, 1999a; Finsterle, 1997) and T2R3D V1.4 (Lawrence Berkeley National Laboratory, 1999b; Wu, et al., 1996), is used to simulate flow and transport behavior in the Alcove 8-Niche 3 tests. Pretest predictions are based on an extensive calibration process that explicitly incorporates observed variations in infiltration and seepage during the early part of the Phase I flow testing. A table of calibrated rock properties for the model domain is provided (Bechtel SAIC Company, LLC, 2003a). Other important model values, such as fracture spacing and gamma, are not explicitly listed but are assumed to be similar to those used in previous pretest predictions (Ziegler, 2002).

Quantitative graphical depictions of flow and transport predictions for the remainder of the Phase I and Phase II flow and tracer tests are presented in the DOE response. The predictions account for flow changes, differences in matrix diffusion coefficients between tracers, and expected (based on the limited information available) fracture communication between infiltration plots and seepage collection trays.

The DOE response also provides a discussion of major uncertainties involved in the pretest predictions and interpretation of the test results. Three major uncertainties are identified. First, connectivity of water flow paths between infiltration plots and seepage trays is largely unknown and is limited by the available information about the fracture network. It is likely, however, that results of initial tracer testing will help to improve characterization of the connectivity for subsequent tests. Second, mechanisms that could cause an enhancement of matrix diffusion are not well understood. In the fault test, the effective matrix diffusion coefficient used in the numerical model had to be increased to properly match the test results. It is uncertain whether similar results will be observed for the large plot test. Third, there is considerable uncertainty in the conceptual understanding of the temporal variability of observed infiltration rates. For instance, infiltration into the plots was expected to be highest initially and to decrease as the system approached steady state. Instead, several plots showed large variations in infiltration rate over time (e.g., plots 5, 7, 8, 9 and12 in Figure E-5) (Bechtel SAIC Company, LLC, 2003a, Appendix E). Potential mechanisms and controlling factors for these observations are largely unknown, and the influence of the temporal variability on effective fracture permeability is unclear. The DOE response cautions that this issue may prevent achievement of the test objectives that attempt to relate permeability and water potential in the fracture network.

4.0 NRC EVALUATION AND COMMENTS

4.1 Agreement USFIC.4.06

As summarized in Section 3.1 of this review, the DOE response to Agreement USFIC.4.06 (Bechtel SAIC Company, LLC, 2003a, Appendix D) provides rationale to justify the appropriateness of the continuum modeling approach for predicting drift seepage. Summaries of modeling studies that consider effects of discrete-fractures on seepage predictions also are provided.

The purpose of Agreement USFIC.4.06 was to obtain a commitment from DOE to provide results from the ongoing modeling studies to evaluate two different approaches to modeling drift seepage: a heterogeneous fracture continuum modeling approach and a discrete-fracture network modeling approach. The continuum approach refers to the use of a numerical modeling grid that implicitly assumes hydrologic properties are uniformly distributed within grid cells, and cell-to-cell flow is assumed to occur between the entire contact area of adjacent grid cells. A discrete-fracture network model generally refers to an approach in which flow is modeled as a network of linear or planar features, and flow from one location to another in a model domain can occur only if the two locations are connected by a pathway of interconnected features. A staff concern underlying Agreement USFIC.4.06 was that the increased area of hydraulic connection between model grid cells in the continuum-based approach could result in predictions of greater capillary diversion of water around drift openings than might actually occur in networks of individual fractures.

Staff note that the modeling studies cited in the DOE response (Finsterle, 2000; Liu, et al., 2002) are not considered discrete-fracture network models as described in the language of the agreement. For example, the Finsterle (2000) study used a numerical continuum model that treated individual fractures as lines of cells with permeabilities higher than adjacent cells and with capillary strength inversely correlated to permeability. This approach was referred to as a discrete-feature model. The Liu, et al. (2002) study used stochastically generated fracture networks and a set of constitutive equations as the basis for assigning hydrologic properties to the grid cells of a continuum model; cell permeability was based on the number of corresponding fracture connections and capillary strength was based on average fracture apertures. Thus, the discrete-feature models used in the Finsterle (2000) and Liu, et al. (2002) studies were continuum models with refined grids and permeability distributions designed to represent the permeability distributions of fracture networks. While these models are not true discrete-fracture network models, they do explicitly include representation of discrete fractures and, thus, provide insight into whether continuum models with stochastic heterogeneity distributions can provide seepage predictions consistent with the behavior of flow in discrete fractures.

Staff agree with the DOE position that the heterogeneous fracture continuum model used for the performance assessment abstraction of drift seepage basically serves as a transfer function for providing average seepage rates applicable to a limited range of hydrogeologic conditions. The discrete-fracture modeling approach, while conceptually appealing for its ability to explicitly represent flow restricted to fractures, also must be thought of as no more than a transfer function in the context of estimating seepage rates at the scale of repository drifts. That is, it is not practicable for a discrete-fracture model to explicitly represent observed fracture patterns for such a large scale. Hence, discrete-fracture models typically are based on underlying statistical models to represent fracture patterns. Additionally, the difficulty of including intrafracture processes, such as flow fingering, film flow, and small-scale variability in moisture retention properties necessitates the use of simplifying assumptions and parameter adjustments that limit the range of hydrogeologic conditions for which the model is applicable. Because of such difficulty in representing discrete fractures, a common approach is to use continuum averaging of broad zones around fractures used with Darcy-based equations to represent the flow processes in fracture planes. This simplifying approach was used to represent fracture networks in the Finsterle (2000) study cited in the DOE response.

The modeling results of Finsterle (2000), cited in the DOE response, demonstrate that stochastic fracture continuum models are capable of providing seepage predictions similar to those of discrete-feature models for a range of input flow rates. One difference between the results presented by Finsterle (2000) for the two modeling approaches relates to the concept of a seepage threshold. Seepage threshold refers to the maximum rate of water percolation that can be diverted around a drift opening by capillary retention before water begins seeping into the drift. Finsterle (2000) showed the seepage threshold from the randomly generated heterogeneous fracture continuum model was about a factor of two greater than the prediction from the discrete-feature model. This result suggests that a continuum model approach could underpredict the amount of drift seepage occurring at low percolation rates, compared to a discrete-feature modeling approach. As suggested by Liu, et al. (2002), however, the apparent difference in seepage threshold might be reduced for a similar comparison using three-dimensional discrete-feature models.

The modeling study of Finsterle (2000) also provides an analysis of the effect of uncertainty on the seepage predictions. Monte Carlo simulations were conducted with the two-dimensional heterogeneous fracture-continuum model to evaluate uncertainty in seepage predictions resulting from variability in the heterogeneous permeability field and uncertainties in the capillary strength parameter. Finsterle (2000) interpreted the results to indicate uncertainty of seepage predictions was mainly attributable to stochastic variability of the hydrologic property field (i.e., different stochastic realizations of spatial heterogeneity in the permeability field). It should be noted, however, the uncertainty range considered in the Monte Carlo simulations for the capillary strength parameter was small ($\log_{10}$ of the standard deviation = 0.15), which would reduce the amount of seepage variability as a result of uncertainty in the capillary strength parameter. It is, thus, not clear that the effects of model parameter uncertainty have been fully explored in these simulations.

An interesting result of the Finsterle (2000) analysis is that, when these alternative modeling approaches were calibrated to produce similar seepage estimates, the calibrated values of the capillary strength parameter for the two models differed by orders of magnitude. The difference in the capillary strength parameter may be mainly attributable to the fact that the two-dimensional, discrete-feature model restricts in-plane flow parallel to the drift axis (i.e., in this two-dimensional model, lateral diversion around drifts could only occur perpendicular to the drift axis). Hence, greater capillary retention is needed to reproduce the amount of flow diversion around drift openings that occurs in three dimensions during *in-situ* tests. These results suggest that, while the concept of capillary strength is physically based on observable features, the appropriate value of this parameter is model dependent and, therefore, best determined by calibrating models to specific *in-situ* seepage tests. Therefore, capillary strength parameter estimates from the Finsterle (2000) two-dimensional heterogeneous continuum model might not be appropriate for the three-dimensional heterogeneous continuum model used by DOE to develop the drift seepage abstraction for performance assessments.

The DOE response presents examples of two cases for which fracture continuum models were calibrated to match seepage observed during liquid release tests in the Enhanced Characterization of the Repository Block Cross Drift (Bechtel SAIC Company, LLC, 2003a, Figure D–1). It is evident in these examples that fracture continuum models are capable of predicting average seepage rates from the liquid-release tests with reasonable accuracy. These examples of model calibrations to *in-situ* tests also show the modeled seepage predictions varied with changes in ambient relative humidity in a manner similar to the observed seepage rates. During these tests, ambient relative humidity varied from as little as 10 percent to nearly 90 percent. Thus, it appears the effects of variable relative humidity on seepage have been appropriately incorporated in these seepage model calibrations and the fracture continuum models are capable of reproducing the resulting evaporation effects.

In addition to the two *in-situ* test calibrations in the DOE response, several other model calibrations to tests in the cited analysis and model report (Bechtel SAIC Company, LLC, 2003b) indicate fracture continuum models are capable of matching a variety of liquid-release test conditions. Staff note, however, these seepage models are calibrated only to match the amount of water captured in drip collection systems during the liquid-release tests. Water that might enter drift openings but then be diverted as film flow along drift walls is effectively treated as capillary diversion in these models. Although film flow along drift walls may not be likely to contact waste packages or drip shields, it could result in greater saturation of drift floors or inverts, thereby reducing or eliminating drift shadow effects and enhancing rates of advection and diffusion in the rock below drifts. Staff, therefore, are concerned that seepage models appropriate for predicting dripping from drift crowns might lead to erroneous conclusions regarding potential rates of advection and diffusion of radionuclides in the near field. For example, while it may be sufficient to treat processes such as flow along drift walls implicitly for predicting dripping at the drift crown, such processes may need to be considered explicitly for modeling drift shadow effects at the drift floor. While this concern is not directly related to the information request of Agreement USFIC.4.06, staff note that assumptions about potential drift shadow effects and water content of drift inverts should be supported by modeling or observation data appropriate for that purpose.

Another staff concern that merits attention is the relationship between seepage and drift degradation within the compliance period. It is not clear if DOE seepage models would be applicable to ambient drift conditions if a natural backfilling process and a change to the symmetry of the drift geometry were to occur relatively early in the 10,000-year compliance period (Gute, et al., 2003). A larger, rougher, irregularly shaped drift ceiling may considerably impede capillary diversion while a completely rock-filled drift might also reduce or eliminate drift shadow effects. The processes related to drift degradation are expected to be included in the Total System Performance Assessment - License Application disruptive seismic scenario modeling case. Staff note that the uncertainty in the potential changes to drift geometry on seepage, and in completely backfilled drift tunnels on postulated drift shadow effects, should be appropriately considered in performance assessment calculations, or shown to be of no consequence.

Staff also note that calibrated seepage model parameters differ among the different tests they are calibrated to match. These differences in calibrated parameters suggest a range of parameter uncertainty that must be considered when using such models to develop a performance assessment abstraction applicable to an entire repository. NRC previously commented on the subject of model uncertainty in the DOE continuum models used to represent flow in fracture networks. In the NRC review of Agreement TEF.2.13 (Schleuter, 2003b), the intent of Agreement TEF.2.13 was summarized as being "… to answer the question, do coarse-grid continuum models using the van Genuchten equations capture the important characteristics of flow in fractured tuffs?" Agreement TEF.2.13 was not considered complete because it still was not clear that components of model uncertainty described in published literature have been integrated into process and performance assessment models. Staff concerns about the incorporation of model uncertainty into the abstraction of drift seepage should be addressed by DOE in response to the additional information needs identified for Agreement TEF.2.13. Additionally, Agreement USFIC.4.01 requests DOE to complete certain underground seepage tests and to use results of those tests to either confirm the existing seepage abstraction or to incorporate those results into an improved abstraction. While staff concerns remain about the incorporation of model and parameter uncertainty into the drift seepage abstraction, those concerns are addressed by other agreements.

Based on the information provided in the DOE response, staff agree the stochastic heterogeneous continuum modeling approach can be appropriate for conditions of multiple connected fractures with variable orientations that allow diversion of water around drift openings. The existence of such conditions in much of the proposed repository horizon is supported by detailed line surveys cited by DOE, indicating fracture frequencies ranging from 3.2 to 4.3 fractures per meter [1 m = 3.281 ft], with three predominant orientations. In summary, NRC staff conclude that the DOE response to Agreement USFIC.4.06 is responsive to the staff concern that a continuum-based modeling approach could result in predictions of greater capillary diversion of water around drift openings than might actually occur in networks of individual fractures. This conclusion is based on results of discrete-feature modeling studies and results of calibrated continuum-based seepage models that accurately reproduce seepage observations from in-situ tests. Staff emphasize, however, that the information provided in the DOE response, while sufficient to complete Agreement USFIC.4.06, also suggests calibrated parameter values for predictive seepage models can depend strongly on model aspects such as grid dimensionality, spatial distribution of heterogeneity, and drift geometry. Staff, therefore, note the need for DOE to demonstrate that model parameters and parameter uncertainty distributions used in the seepage model for performance assessment are appropriate for that specific model formulation. Staff note secondly that, for the nominal scenario, seepage modeling approaches sufficient for estimating the amount of dripping at the drift crown, but not for the amount of flow along the drift walls, may not be appropriate for drawing conclusions about drift-shadow effects at the drift floor. Staff note thirdly that, for the disruptive seismic scenario, the uncertainty related to changes to the symmetry of the drift geometry on capillary diversion and seepage should be appropriately considered in performance assessment calculations, or shown to be of no consequence. Staff note fourthly, that DOE needs to address Comment 2 from the NRC staff review letter dated February 14, 2003 (Schlueter, 2003a). The comment asks DOE to justify its use of a continuum model when the spacing of flowing fractures exceeds the grid size when predicting transport for the Alcove 8-Niche 3 tests.

4.2 Agreements RT.3.06 and SDS.3.02

The DOE response to Agreements RT.3.06 and SDS.3.02 (Bechtel SAIC Company, LLC, 2003a, Appendix E) directly addresses the NRC additional information needs. Pretest predictions for the Phase II component of the Alcove 8-Niche 3 tests are clearly presented and are determined using current plans and information. The DOE response explicitly identifies major uncertainties and limitations regarding the pretest predictions. Comments included in a previous NRC staff response (Schlueter, 2003a), which are to be addressed as part of RT.3.05, SDS.3.01, and USFIC.6.03, are noted.

The pretest predictions for Phase II and the revised predictions for the remaining Phase I tests indicate appropriate inclusion of information gathered from early testing and consideration of some previous NRC comments. For instance, DOE has taken advantage of data collected during observations of infiltration to better inform the model calibration process even though mechanisms for the temporally variable infiltration rates are not yet fully understood. Likewise, modeled initial conditions (e.g., matrix saturation values) for the large plot test predictions were adjusted in an attempt to account for the effects of water added during nearby fault tests. The initial matrix saturation value for each model layer was derived by averaging a value of 1.0 (fully saturated) with the previously estimated initial values for each layer (0.72 for tsw33 and 0.85 for tsw34).

The effort made to identify major uncertainties is particularly relevant to several NRC concerns. For instance, one major uncertainty identified by DOE is a lack of understanding of the mechanisms that impact and enhance matrix diffusion. DOE increased effective matrix diffusion coefficients in their models by adjusting the fault (fracture)-matrix interface area to match observed fault test results, but the impact of fault proximity and whether fractured rock away from the fault will behave similarly are largely unknown. Previous NRC comments (Schlueter, 2003a) have raised concerns about the ability to interpret test results considering the potential for disequilibrium in the test conditions, possible hysteresis-type effects during saturation and desaturation, and lack of mass balance, all of which could contribute to this uncertainty. Acknowledgment and attempts to account for these uncertainties, as expressly identified in the DOE response, will be of benefit for understanding not only the limitations of parameters used in the modeling approach but also limitations of meso-scale experiments. This information could be used in the design and operation of performance confirmation activities.

The DOE response explicitly notes "... the tests do not provide results that directly support the development or abstraction of unsaturated zone process models for total system performance assessment" (Bechtel SAIC Company, LLC, 2003a, Appendix E, p. E–3). The Alcove 8-Niche 3 experiments, however, have the potential to provide significant information to support understanding of the movement of water through faults and fractures and fracture-matrix interaction mechanisms (e.g., matrix diffusion) in the unsaturated zone. As noted in the DOE response, documentation of the results and analyses from Phase I line fault experiments is to be included in the analysis and model reports (Bechtel SAIC Company, LLC, 2003c,d). These results will be used with available large-plot test results to evaluate the DOE understanding of flow and transport processes potentially important to performance.

A related agreement item, Agreement TSPAI.3.25, states that field test data, such as that obtained from the Alcove 8-Niche 3 tests, will either provide additional confidence in or a basis for revising the TSPA seepage abstraction and associated parameter, or that DOE should provide a technical basis for not using the field test data. If the DOE does not use the field test data from the Alcove 8-Niche 3 tests for the purpose stated above, NRC staff will be looking for, and subsequently reviewing, the actual technical bases used to support unsaturated zone flow and transport processes, including matrix diffusion. Another related agreement item, Agreement SDS.3.01, states that for the Enhanced Characterization of Repository Block long-term test and the Alcove 8-Niche 3 tests, any observed seepage will be related to full periphery maps and other fracture data in testing documentation. The constructed full-periphery map of Niche-3 fractures should be used to indicate where seepage occurred during the Alcove 8-Niche 3 tests, in both qualitative and quantitative terms. To fracture-inform these tests, the following correlations could be documented: between seepage locations and local fracture density, between fracture apertures at seepage locations and the aperture statistics of the overall fracture population, and between fracture intersections, terminations, or intra-fracture aperture variability and the occurrence of seepage. In addition, the influence of fractures in determining the type of seepage such as dripping or film flow along the drift walls should be documented qualitatively. Various parameters and assumptions such as Van Genuchten alpha (α_f), flow focusing factor, active-fracture parameter, heterogeneity correlation scale, and effective fracture aperture, spacing, and porosity, may be confirmed using the fracture information from the Alcove 8-Niche 3 tests.

Based on the foregoing considerations, staff consider Agreements RT.3.06 and SDS.3.02 complete. It is noted, however, the DOE responses to Agreements RT.3.06 and SDS.3.02 cite revised documents that were not publicly available at the time of this review. If in DOE's license application the effects of unsaturated zone flow and transport processes, including matrix diffusion, are determined to be important to the description of the capability of a barrier important to waste isolation, then staff could review this formal documentation when it is available.

5.0 SUMMARY

The NRC staff evaluated the DOE responses to key technical issue agreements, which were contained in appendixes to Bechtel SAIC Company, LLC (2003a). The specific agreements evaluated were USFIC.4.06, RT.3.06, and SDS.3.02. The NRC staff concluded the information provided by DOE to address these three agreements is responsive to the original staff concerns.

It is noted, however, the DOE responses to Agreements RT.3.06 and SDS.3.02 cite revised documents that were not publicly available at the time of this review. If in DOE's license application the effects of unsaturated zone flow and transport processes, including matrix diffusion, are determined to be important to the description of the capability of a barrier important to waste isolation, then staff could review this formal documentation when it is available.

6.0 STATUS OF THE AGREEMENTS

Agreement USFIC.4.06 is complete.

Agreement SDS.3.02 is complete.

Agreement RT.3.06 is complete.

7.0 REFERENCES

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