May 16, 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: REVIEW OF DOCUMENTS PERTAINING TO AGREEMENT THERMAL EFFECTS ON FLOW (TEF).2.13 (STATUS: NEED ADDITIONAL INFORMATION)

Dear Mr. Ziegler:

In your letter dated January 21, 2003, the U.S. Department of Energy (DOE) enclosed a response to Agreements Total System Performance Assessment (TSPAI).3.18, TSPAI.3.21, TSPAI.3.23, Thermal Effects on Flow (TEF).2.13, and General (GEN).1.01, Comments 18, 24, and 69. The enclosed report documented technical information and associated references, the physical relationship of the unsaturated flow system on barrier capabilities of the proposed repository, and sensitivity analyses for risk importance. The U.S. Nuclear Regulatory Commission (NRC) staff has reviewed this information, with respect to Agreement TEF.2.13, and the results of the staff's review are enclosed. Separate NRC review letters will be prepared for Agreements TSPAI.3.18, TSPAI.3.21, and TSPAI.3.23 (including comments from GEN.1.01).

Agreement TEF.2.13 states that DOE will provide Revision 01 of both the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport and the Analysis of Hydrologic Properties Analysis and Model Reports. A DOE presentation at the TEF technical exchange and management meeting in January 2001 described the two specific concerns underlying this agreement. One, addressing the uncertainty of treating fractures as a continuum through the use of discrete fracture models and assess the impact on seepage. Two, assessing the appropriateness and applicability of the van Genuchten constitutive relations, which were based on granular porous media models, for flow occurring along fracture planes.

In the report submitted for Agreement TEF.2.13, DOE provided a discussion on why heterogeneity was unimportant to the distribution of vertical flux. The report also noted that flow focusing factors were stochastically incorporated into the performance assessment to represent the effect of heterogeneity. The report did not provide a transparent discussion of the concerns identified at the TEF technical exchange and management meeting of January 2001.

The DOE report also provided results from dose-based, sensitivity studies in order to demonstrate that the current understanding of percolation and seepage processes is adequate given that it has little significance to the calculation of the mean annual dose in the first 10,000 years following waste emplacement. The risk sensitivity studies provided are not sufficiently documented to have supported the completion of Agreement TEF.2.13 on the basis of low risk significance. Additional risk information is needed if DOE chooses to complete Agreement TEF.2.13 based upon risk assessments and sensitivity analyses. Guidance on the use of risk information to complete agreements was provided by NRC in its letter to DOE titled, "Use of Risk as a Basis for Closure of Key Technical Issue Agreements," dated January 27, 2003.

Additional information as described in the attachment is needed to complete the key technical issue Agreement TEF.2.13. DOE may choose to complete Agreement TEF.2.13 by either providing: 1) additional technical information as discussed in Section 4.1 of the attachment including a technical basis demonstrating that: (i) preferential flow in fractures is not masked by the volume-averaging of coarse grid cell in continuum models; (ii) appropriate heterogeneity representing fractures has been incorporated into the models; (iii) the van Genuchten relations and parameters are appropriate for unsaturated flow in fractures; and (iv) the model uncertainty noted above have been addressed in all appropriate hydrologic and thermohydrologic process and abstraction models; or 2) additional risk information as discussed in Section 4.3 of the attachment. With regard to the latter option, the disposition of Agreement TEF.2.13 can be determined after DOE adequately addresses NRC's concerns with its approach to resolving agreements via risk arguments and sensitivity analyses as discussed in the January 27, 2003, risk letter.

The NRC's interest in the information requested in the agreements is to support a detailed review of the potential license application. The NRC will consider risk information provided by DOE in conjunction with other factors, when evaluating whether sufficient information exists for NRC to conduct a detailed review of a potential license application. Consequently, the NRC may need to continue to request the original information sought in an agreement if we are not satisfied that the risk-information provided is adequate.

The key technical issue Agreement TEF.2.13 has the status "need additional information." If there are any questions regarding this letter, please contact Bill Dam 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

Attachment:
NRC Review of DOE Documents Pertaining to Key Technical Issue Agreement TEF.2.13

cc: See attached distribution list

years following waste emplacement. The risk sensitivity studies provided are not sufficiently documented to have supported the completion of Agreement TEF.2.13 on the basis of low risk significance. Additional risk information is needed if DOE chooses to complete Agreement TEF.2.13 based upon risk assessments and sensitivity analyses. Guidance on the use of risk information to complete agreements was provided by NRC in its letter to DOE titled, "Use of Risk as a Basis for Closure of Key Technical Issue Agreements," dated January 27, 2003.

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NRC Review of DOE Documents Pertaining to Key Technical Issue Agreement TEF.2.13

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Letter to J. Ziegler from J. Schlueter, dated: May 16, 2003
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V. McQueen, Sr., Ely Shoshone Tribe
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D. Eddy, Jr., Colorado River Indian Tribes
H. Jackson, Public Citizen
J. Wells, Western Shoshone National Council
D. Crawford, Inter-Tribal Council of NV
I. Zabarte, Western Shoshone National Council
NRC On-Site Representatives

NRC Review of DOE Documents Pertaining to Key Technical Issue Agreement TEF.2.13

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. Also, and just as importantly, 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 Key Technical Issue (KTI) Agreement Thermal Effects on Flow (TEF).2.13, which was reached between NRC and DOE during a technical exchange and management meeting[1]. This agreement pertains to model uncertainty, specifically in regard to the continuum representation of flow in fractured rocks and the development of appropriate hydrological properties to use in the continuum model. This agreement was addressed by DOE in a letter[2] and in the enclosed report (Rickertsen, 2003), which are the subject of this review.

1 WORDING OF THE AGREEMENT

TEF.2.13 states: "Provide the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport AMR [Analysis Model Report], Rev. 01 and the Analysis of Hydrologic Properties Data AMR, Rev. 01. The DOE will provide updates to the Conceptual and Numerical Models for UZ Flow and Transport (MDL–NBS–HS–000005) Rev 01 and the Analysis of Hydrologic Properties Data (ANL–NBS–HS–000002) Rev 01 AMRs to the NRC. Scheduled availability is FY02."

2 BACKGROUND

Open item 8 of TEF Subissue 2 (thermal effects on temperature, humidity, saturation, and flux) requested that model uncertainty be considered in thermohydrologic process models used to support performance assessment (NRC, 2000). An assessment of model uncertainty should consider results from reasonable alternative conceptual models for flow and transport in the unsaturated, fractured tuff environment of Yucca Mountain. Equivalent continuum, dual-continuum (e.g., dual-permeability), and active-fracture models were specifically mentioned by NRC (2000) as flow conceptualizations that DOE has evaluated. These conceptualizations represent an evolution of continuum models to better represent unsaturated flow in the fractured tuffs at Yucca Mountain. The most recent one, the active-fracture model, is a revision to the dual-permeability model that makes the matrix/fracture interaction dependent on fracture saturation. While intending to include the effect of a portion of fractures and a portion of particular fracture surfaces participating in flow, the active-fracture model still has the potential to mask preferential (rivulet) flow by spatial averaging.

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

[2]Ziegler, J.D. "Transmittal of Report Addressing Key Technical Issue (KTI) Agreement Items Total-System Performance Assessment and Integration (TSPAI) 3.18, 3.21, 3.23, and Thermal Effects on Flow (TEF) 2.13." Letter (January 21, 2003) to J. Schlueter.

Two underlying concerns from NRC (2000) remain. One, preferential flow in discrete fractures may be inadequately represented by the volume averaging approaches inherent in continuum models unless sufficiently refined grid cells are used. Refluxing during the thermal period and the potential breaching of the dryout zone by transient or steady fingers or rivulets of water along a fracture is a particularly relevant example for Agreement TEF.2.13. Two, constitutive relations based on granular porous media models, but applied to fracture networks, may not be applicable to flow occurring on a single face of a fracture. Scaling of properties developed using appropriate conceptualizations for fracture flow that address these underlying issues, while relevant for models at all scales, is particularly important for drift-scale (seepage) models.

Consistent with this understanding of the topic of Agreement TEF.2.13 is the DOE presentation on addressing open item 8 at the TEF technical exchange and management meeting[3] (Bodvarsson presentation cited on page 8 of meeting summary). In the presentation, the basis for resolution included the consideration of (i) types of model uncertainty; (ii) flow conceptualization under ambient and thermal conditions; (iii) fracture flow under ambient and thermal conditions; (iv) fracture-matrix interaction; (v) discrete fracture description; and (vi) reducing modeling uncertainty, generally through the use of data from field tests. In particular, page 10 of the Bodvarsson presentation noted that model uncertainty from fracture flow under ambient and thermal conditions, including matrix/fracture interactions and the active fracture model, were to be included in Revision 01 of CRWMS M&O (2000a). On pages 14, 18, and 19 of the Bodvarsson presentation, uncertainty from treating the fracture network as a continuum and the use of discrete fracture models to support the continuum approximation were to be incorporated into Revision 01 of CRWMS M&O (2000b). Page 14 of the Bodvarsson presentation discusses the use and goals of discrete fracture modeling, and pages 18 and 19 discuss the appropriateness of the van Genuchten relation for the fracture continuum. These two DOE proposed revisions of analysis model reports are the ones cited in Agreement TEF.2.13.

Many models of unsaturated flow at Yucca Mountain rely on the conceptualization of fracture flow and fracture continuum parameterization described in CRWMS M&O (2000a) and CRWMS M&O (2000b). The site-scale unsaturated ambient and thermohydrological models, thermal seepage model, and the multi-scale thermohydrological models all directly use continuum properties developed using the approach described in CRWMS M&O (2000b). Actual parameters used in these models are estimated through calibration using the three-dimensional site-scale ambient unsaturated flow model. All of these models use homogeneous properties for each hydrostratigraphic layer, but different layers use different property values. Another process model, the drift seepage model, incorporates heterogeneous properties and a fine grid {0.5 m [1.6 ft] near the drift}. All of these models use the same continuum approximation for the fracture network. The DOE approach for reducing model uncertainty includes matching numerical model results with data from various field experiments at Yucca Mountain. Of particular note are the injection tests in Niche 3650, the ongoing injection tests in a fault in Alcove 8/Niche 3, the Single Block Heater Test, the Drift Scale Heater Test, and the planned Cross-Drift Thermal Test. The objectives of the ongoing and planned tests were to provide support for the conceptualization and parameterization of continuum models for unsaturated fracture flow. The use of field tests to support conceptual models, however, is part of Agreement TEF.2.12.

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[3]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, 2001) to S. Brocoum, DOE.

In summary, the fundamental concern of NRC staff is the uncertainty of using a continuum representation of unsaturated flow in fractures and the appropriateness and development of unsaturated constitutive relations used for the fracture continuum that were originally developed for granular porous media. The two analysis model reports cited in Agreement TEF.2.13 specifically pertain to these concerns, and, in general, were intended to address the general topic of model uncertainty for site-scale and drift-scale ambient and thermohydrologic models.

3 NRC REVIEW

The Rickertsen (2003) report provides three areas of discussion to support the completion of Agreement TEF.2.13. First, technical information and associated references are provided to support the DOE conclusion that heterogeneity is appropriately considered in DOE total-system performance assessments. Second, the physical relationship of the unsaturated flow system on barrier capabilities of the proposed repository is discussed. Third, analyses of sensitivity of total-system performance to bounding cases of infiltration, seepage, and unsaturated flow and transport are provided. Though Agreement TEF.2.13 was classified as a bin 3 agreement, DOE provided both technical evidence and risk information to support closure of the agreement. DOE concluded that they consider Agreement TEF.2.13 to be fully addressed and recommended that, upon the NRC review and acceptance of this submittal, the agreement be considered completed.

3.1 Review of Technical Information and Associated References

In Section 2.1.4 of Rickertsen (2003), DOE explains the rationale for including Agreement TEF.2.13 with the submittal for Agreements TSPAI.3.18,TSPAI.3.21 and TSPAI.3.23. DOE maintains that the underlying intent of Agreement TEF.2.13 is addressed by the more specific requests in the TSPAI agreements. The specific linkage cited is that spatial heterogeneity is the underlying issue for addressing the model uncertainty of using continuum representations for discrete fractures and fracture flow under unsaturated conditions. In Section 2.1.3 of Rickertsen (2003), a couple points are made on lateral heterogeneity. One, heterogeneity is stated as being unimportant to the distribution of vertical flux because “flow from the surface to the repository is gravity dominated.” The vertical unsaturated hydraulic conductivity is said to be in excess of that needed for gravity drainage. Two, flow focusing factors, stochastically ranging from a lower limit of 1 to an upper limit of 9.7 to 47, are used in performance assessments to represent the effect of spatial heterogeneity.

Rickertsen (2003) also explains the assessment that bomb-pulse Cl-36 data found below the Paintbrush tuff can be linked to a negligible amount of fast flowing water. First, bomb-pulse Cl-36 has been indicated in samples at relatively few locations in the Exploratory Studies Facility, and these samples are generally located in or near fault or fracture zones. Second, perched water samples from Yucca Mountain do not bear Cl-36 signatures, and have apparent C-14 ages on the order of thousands of years. Additionally, the site-scale unsaturated flow model does include fast pathways associated with the few, explicitly included, large fault systems in which model travel times to the repository level can occur within 50 years for approximately one percent of initial infiltration.

3.2 Review of the Physical Relationship of Unsaturated Zone Heterogeneity on Barrier Capabilities of the Proposed Repository

In Section 2.2 of Rickertsen (2003), the role of unsaturated zone heterogeneity on the barrier capabilities of the proposed repository system is discussed. Basically, heterogeneity can cause focused flow paths that may result in increased seepage rates. As conceptualized in the DOE performance assessment model, increased seepage would mean a larger fraction of drip shields would be in an aqueous environment, rather than just a humid environment, for more of the time. Rickertsen (2003) speculates that increased seepage would make the environment for drip shield corrosion more benign because of dilution and the presence of corrosion inhibiting ions, such as nitrate, in seepage water. In the event of drip shield failure, increased seepage would also cause a larger fraction of waste packages to be in an aqueous environment. Rickertsen points out, however, that DOE studies show that corrosion rates for Alloy 22 are similar for aqueous and humid air environments, implying that higher seepage would not substantially affect waste package lifetimes. In the event of a waste package failure, increased seepage could cause more water to contact waste and also increase transport velocity in the drift invert and the unsaturated zone below the repository. Both of these latter effects (i.e., more water contacting waste and faster transport velocity) would be expected to have some effect on total-system repository performance. As shown in the Section 2.3 on sensitivity, Rickertsen (2003) presents dose-based sensitivity analyses that provide insight on the significance to risk of increased infiltration and seepage, and faster contaminant transport rates.

3.3 Review of Sensitivity Analyses for Risk Importance

In Section 2.3 of Rickertsen (2003), the total-system sensitivity analyses include three types of analyses: (1) a comparison of mean dose estimates between a case where the basecase net infiltration is used and a case where net infiltration is set to an extreme value approximately equal to the present-day mean annual precipitation; (2) a comparison of mean dose estimates between an expected seepage case with an average seepage rate of less than 0.1 m^3/yr (26 gal/yr) over approximately half the packages, and a bounding case where seepage is set to 1.0 m^3/yr (260 gal/yr) over all waste packages; (3) a comparison of dose estimates between the expected case and cases where flow and transport parameters are computationally neutralized (i.e., radionuclides are assumed to be released directly into wells in Amargosa Valley). Three types of sensitivity analyses are each made by Rickertsen (2003) for two scenarios: a nominal scenario for otherwise expected conditions, and an igneous activity groundwater release scenario in which magma is assumed to damage waste packages and drip shields in a portion of the repository. The extreme seepage scenario is more directly relevant to Agreement TEF.2.13 than the extreme net infiltration scenario, and thus is emphasized in the summary below.

For the nominal scenario, results indicate that dose estimates are marginally higher for the extreme seepage case compared to the basecase; the increased mean annual dose is approximately 10 percent. The lack of sensitivity of the nominal case to the seepage rate can be attributed, in part, to the benefits of the drip shield, which is modeled to be effective at preventing advective releases of radionuclides by reducing the water that drips onto the waste package and water that enters the invert. The sensitivity studies suggest that highly soluble radionuclides (e.g., C-14 and Tc-99) dominate the dose estimates. Because the inventory of these highly soluble radionuclides is quickly exhausted even at relatively low seepage rates, modeled dose rates do not change significantly with increased seepage. The exhaustion of the inventory of highly soluble radionuclides may explain the reduction in dose for the extreme seepage case during the 10,000- to 50,000-year (approximate) period. However, increased seepage would also result in increased wetting of the drift invert, which accommodates slightly higher diffusive release rates. Increased seepage also increases flow velocity below the repository, reducing radionuclide travel time to the water table. No quantitative comparisons of radionuclide diffusion through the inverts or unsaturated zone transport velocities are provided in the DOE report.

Sensitivity of mean dose estimates to seepage rates are also presented for the igneous activity groundwater scenario. In this scenario, mean annual dose estimates represent the dose resulting from groundwater pathways following an igneous intrusion. Drip shields and waste packages are assumed to be breached following the igneous activity. Information regarding the timing of igneous events for each realization is not provided in the DOE report, but Bechtel SAIC Company, LLC (2002) indicates that the timing of the igneous event is stochastically sampled over the 100,000-year simulation period. The dose estimates for the extreme seepage case vary from 100 times greater than the dose estimates using the basecase seepage rates in the igneous activity scenario early in the performance period to 5 times the dose later in the performance period. The dose, however, remains below 0.0002 mSv [0.02 mrem] during the performance period for the extreme seepage scenario, which is substantially below the 0.15 mSv [15 mrem] regulatory limit. The sensitivity study presented in the DOE report explains that increased dose estimates for the igneous groundwater scenario and that increased sensitivity to extreme seepage (compared to the nominal case) are the result of the breached drip shields and waste packages, which permit advective flow to contact the waste.

For the sensitivity analyses of complete neutralization of flow and transport, mean doses for both the nominal scenario and igneous scenario were modeled to arrive much earlier, as would be expected. Although the mean dose rates modeled for these scenarios were two to three orders of magnitude greater than the basecase dose estimates, the peak doses remained significantly below the 0.15 mSv [15 mrem] regulatory limit during the 10,000-year compliance period.

The Rickertsen (2003) report concludes that “uncertainties in the representation of the unsaturated zone flow system described in these KTI agreements do not play a significant role in determining whether the individual protection requirement would be met. Similar conclusions would be drawn with respect to the determination regarding the groundwater protection requirements.”

4 NRC COMMENTS AND CONCLUSIONS

4.1 NRC Comments on Technical Information and Associated References Pertaining to Spatial Heterogeneity and Fast Paths

The relevant discussion for Agreement TEF.2.13 at the technical exchange and management meeting[4] was whether or not the distribution of flow in fractures, particularly flow along fracture planes, was captured in appropriate DOE models for ambient and thermally-perturbed conditions at Yucca Mountain. The uncertainty of treating fractures in coarsely-gridded continuum models (relative to their actual dimensions) was to be assessed through the use of small discrete fracture models. The effect on seepage was of particular importance for the discrete fracture analysis. Pruess (1999) summarized evidence (field, laboratory, numerical, and theoretical) that suggests water flows in episodic pulses of fingers and rivulets and as thick films in fractures such as those in the proposed repository horizons of Yucca Mountain. In general, the objectives of the modeling and the characteristics of the fractured rock dictate how to account for flow processes in fractures. For large scale models (mountain scale), sufficient detail of the large-scale distribution of flow may be obtained using coarse-grid cells. For small-scale models (e.g., seepage models, drift-scale models), however, capturing preferential flow may change important model results. Volume-averaging of continuum models would mask the preferential flow that would alter the current DOE models of a seepage

[4]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, 2001) to S. Brocoum, DOE.

threshold and no liquid water breaching the dry-out zone. In addition, the van Genuchten equations are assumed to be valid for the describing the constitutive relations for saturation, pressure, and relative permeability for fractures. The intention of Agreement TEF.2.13 was to answer the question, do coarse-grid continuum models using the van Genuchten equations capture the important characteristics of flow in fractured tuffs?

Two concerns on model uncertainty were to be addressed in Agreement TEF.2.13. The first concern is that unsaturated zone flow models may not adequately represent preferential flow along a fracture. Preferential flow includes finger-flow breaching the boiling isotherm and rivulets under ambient (or low temperature) conditions seeping into drifts in contradiction to the seepage threshold concept. Flow along discrete fracture planes may not be well-represented by coarse-grid continuum models used by DOE for unsaturated flow. For example, the theoretical development of Phillips (1996) for the phenomenon of liquid flow along a fracture in a heated rock shows that it is a small-scale process that would not be captured by coarse grid continuum models. Birkholzer, et al. (2003) developed a revised approach for water breaching the dry-out zone by accounting for the episodic nature of fracture flow. An alternative approach to represent preferential flow along a fracture is to finely discretize a continuum model and apply an appropriate distribution of heterogeneous properties. Based on changes to seepage results in numerical analyses, Pruess (1997) concluded that a grid resolution of 0.2 m [0.65 ft] was needed to capture seeps moving into a heated rock along a fracture. In addition to grid resolution, the appropriate 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 the discrete fracture pattern led to simulation results that indicated the drift no longer acted as an effective capillary barrier. The role of fine fractures, and assumptions pertaining to their interconnectedness, could also influence simulation results. Liu et al. (2002) postulated, however, that a three-dimensional model may lead to less seepage than the two-dimensional example they presented. None of these models accounted for the prominent lithophysal content of the lower lithophysal layer of the Topopah Spring unit.

Though not discussed in Rickertsen (2003), the DOE provided clarification on current revisions for the license application reports in a February 6, 2003, teleconference call. The DOE indicated that a model with a refined grid and heterogeneity would be documented in a revision to CRWMS M&O (2000c). This refined model was being developed to support the representation of seepage in the thermohydrologic models while also addressing the O.M. Phillips analytical solution for preferential flow along a fracture breaching the dryout zone (will be addressed in the future under Agreement TEF.2.08). While Agreement TEF.2.08 addresses the specific instance of preferential flow breaching the dry-out zone, Agreement TEF.2.13 addresses the more general case of preferential flow for ambient conditions, in the dry-out zone, and later in the performance period after the dryout zone has rewet.

DOE uses different models (isothermal, nonisothermal) to represent different portions of the domain, with some models providing results to abstractions and other models providing results to other process models. One example of a model that is not fully integrated in the performance assessment is the two-dimensional thermohydrological model (CRWMS M&O, 2001) used to estimate temperature and relative humidity at the waste package. This drift-scale model does not incorporate the focusing factors or key elements of the seepage model or flow focusing factors. Model uncertainty should be carried through to estimates of in-drift temperature and relative humidity that are critical for corrosion models used for waste packages. Results accounting for model uncertainty (e.g., preferential flow) should be integrated in ambient and thermohydrological process models and the performance assessment model.

The second concern of Agreement TEF.2.13 was the appropriateness of the van Genuchten relations for conditions and flow in fractures. The discussion in Rickertsen (2003) on heterogeneity and fast path flow does not directly address this concern, but addresses the effect indirectly through sensitivity analyses. Field tests at Yucca Mountain to support the parameterization of the van Genuchten relations for fractures and faults were planned for Alcove 8/Niche 3 and Niche 5, which would be documented as part of Agreement TSPAI.3.25. In addition, ongoing tension infiltrometer tests along the Enhanced Characterization of the Repository Block drift may shed some light on appropriate van Genuchten parameters. Alternatively, theoretical developments that account for flow processes in unsaturated fractures may also be used to support the use of the van Genuchten relations and associated parameters.

The use of both a flow focusing factor and heterogeneity in the seepage abstraction model could bound the effect of model uncertainty for discrete fracture flow and the appropriateness of the van Genuchten relation for a fracture continuum model. The Rickertsen (2003) report points out that flow focusing caused by heterogeneity above the potential repository horizon is also accounted for by using flow focusing factors that vary stochastically from a value of 1 to an upper limit value ranging between 9.7 or 47, depending on the representation of intermediate scale percolation distribution. This flow focusing factor is used as a multiplier for the input flux to the drift seepage abstraction to account for heterogeneity at scales in between the grid scales of the seepage model and the site-scale unsaturated zone flow model (CRWMS M&O, 2000d). A supporting basis for the lognormal distributions of the flow focusing factors that adequately reflects the aspects of model uncertainty relevant to Agreement TEF.2.13 was not presented in Rickertsen (2003). In CRWMS M&O (2000d), the mean values, the log normal distribution, and the ranges do not transparently incorporate the uncertainty of using continuum models for discrete fracture flow and using van Genuchten relation for fractures. The maximum focusing factor, however, is calculated using the active-fracture model incorporated into the calibrated three-dimensional site-scale unsaturated flow model. Thus, the focusing factors depend on the calibrated site-scale model. It is noted that, complementary to Agreement TEF.2.13, DOE has agreed to use the results of ongoing *in situ* tests to provide additional support for the flow focusing factor parameter values used in performance assessments for Agreement TSPAI.3.25.

In conclusion, it is not clear that components of model uncertainty described in published literature (Birkholzer, et al., (2003), Liu, et al., (2002), Phillips (1996), Pruess (1997,1999)), and discussed above in the context of Agreement TEF.2.13, have been integrated into process and performance assessment models. Additional information is needed to demonstrate that model uncertainty has been addressed from two perspectives. One, flow focusing factors used for seepage in the performance assessment account for model uncertainty related to the use of the van Genuchten relation for fractures and coarsely-gridded continuum models for fracture networks to simulate flow in the unsaturated zone. The active-fracture model and the WEEPS model were used to bound the flow focusing factors, however, the distribution of flow focusing factors requires technical bases that account for (i) preferential flow in fractures that is not masked by the averaging inherent in coarsely-gridded continuum models; (ii) appropriate heterogeneity reflecting discrete fractures; and (iii) van Genuchten relations and parameters appropriate for unsaturated flow in fractures. Two, the drift-scale model used to estimate environmental conditions (i.e., temperature and relative humidity) in the drifts does not incorporate the focusing factors or key elements of the seepage model or flow focusing factors. The two-dimensional thermohydrological model in CRWMS M&O (2001) is used to estimate temperature and relative humidity at the waste package. The DOE should provide support that model uncertainty has been adequately carried through to estimates of in-drift temperature and relative humidity that are critical for corrosion models used for waste packages.

4.2 NRC Comments on the Physical Relationship of Unsaturated Zone Heterogeneity on Barrier Capabilities of the Proposed Repository

NRC staff believe that the complex processes that might affect the chemistry of seepage water and the resulting effects on corrosion rates for drip shields and waste packages are not sufficiently understood to provide confidence in conclusions that increased seepage would have either minimal or beneficial effects on corrosion rates. For example, increased seepage could be a source of moisture in the air available to support cold trap processes (convection and condensation), and when mixed with reflux or ambient percolating water, leads to a high uncertainty for the chemistry of water contacting drip shields or waste packages. Other key technical issue agreements, such as Agreement Evolution of the Near-Field Environment (ENFE).2.06 and Agreement ENFE.2.09, are focused on obtaining a better understanding of the potential range of local chemical conditions that may occur on drip shield and waste package surfaces.

4.3 NRC Comments and Conclusions on Sensitivity Analyses for Risk Importance

The sensitivity analyses outlined by Rickertsen (2003) provide useful insight into the risk importance of seepage and flow in the unsaturated zone in a total system performance assessment context and, combined with existing site data, may ultimately provide a sufficient basis for resolution of Agreement TEF.2.13. However, the risk sensitivity study provided is not sufficiently documented to support the completion of Agreement TEF.2.13 on the basis of low risk significance. In a recent letter[5], NRC staff have previously relayed to DOE that additional information is needed when using risk as a basis to complete key technical issue agreements. First, an analysis of combined uncertainty for all of the key technical issue agreements that are to be addressed using the low risk significance argument is required. Second, DOE should provide an adequate description of the sensitivity analyses completed. Third, some measure of how the variability of results changes between the different modeled cases is needed, because only the mean results of the stochastic performance assessment simulations have been presented to date. For example, presentation of the 5th and 95th percentiles of annual dose estimates, in addition to the mean dose estimates, would be a satisfactory way of conveying the variability and uncertainty of performance assessment estimates. These information needs apply to the DOE sensitivity analyses provided in the response to Agreement TEF.2.13. The three areas of information missing from these sensitivity analyses are described in more detail below.

1. The combined effect of uncertainties (for all agreements addressed with a risk argument) needs to be evaluated before the individual uncertainties can be dropped from further consideration. Otherwise, one could have the situation where moderate increases in risk are considered insignificant but, if numerous uncertainties are addressed in this manner, the combined effect could be significant even when using a risk-based performance metric.

   If agreements in other areas (e.g., waste package corrosion, spent nuclear fuel dissolution) that influence total-system performance assessment model results were not to be resolved via

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[5]Schlueter, J.R. "Use of Risk as a Basis for Closure of Key Technical Issue Agreements." Letter (January 27, 2003) to J.D. Ziegler, DOE.

the use of risk-information in lieu of the originally agreed upon information, then there would be no need to evaluate the combined effects of uncertainties. However, it is the NRC's understanding that this is not the case. For example, the letter report for Agreement TSPAI.3.03 analyzed the sensitivity of the drip shield by means of neutralization, while the analyses for Agreement TSPAI.3.22 showed the sensitivity results of neutralizing natural barrier flow parameters and natural barrier flow and transport parameters. An adequate combined effects uncertainty analysis is needed as discussed in the January 27, 2003 letter from Schlueter (NRC) to Ziegler (DOE).

2. To further support the analysis results, DOE should provide an adequate description of the analysis (e.g., changes to the models, discussion of results) completed to evaluate the sensitivity cases. It is the NRC's understanding that the record package developed for the analyses contains an adequate description of the changes to the base case total system performance assessment model.

   An adequate description is needed of the changes made to the model for the analyses. Some examples of questions, for which staff currrently do not have adequate answers, are given below.

   - The rationale for the bounding seepage value {1m^3/yr [35ft^3/yr]} in the seepage sensitivity analyses should be made more clear. Using the upper flow rate of the glacial transitional climate state, or the occurrence of focused flow, an argument could be made that the 1m^3/yr seepage is not a bounding value. Transparency and completeness in the description of the implementation of the bounding seepage case supports the risk-based argument. For example, Figure 1 on page 19 of the DOE report[6], on Agreement USFIC.3.02, provides an appropriate amount of information to support the level of uncertainty introduced in the analysis for infiltration rates. The level of uncertainty for the bounding seepage analysis is quite pessimistic compared to the data provided in Figure 1.

   - The DOE needs to update their total-system sensitivity analyses with regards to the groundwater protection standards (nominal scenario only) to support their claim of Agreement TEF.2.13 not playing a significant role in determining whether the groundwater protection standards would be met. The last such analyses were done before December 2000 (CRWMS M&O, 2000e).

3. To convey uncertainty in the analyses, DOE should provide information on the variability of simulation results for the sensitivity cases and base cases—for example, by plotting the 5th and 95th percentiles of dose estimates along with the mean dose estimates.

   Uncertainty and variability in the output of the analysis was not presented, but it is NRC's understanding that this information is readily available.

In addition, results from the engineered barrier system submodels have relegated concerns underlying Agreement TEF.2.13 as unimportant to dose. Therefore, substantiative changes to results from

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[6]Ziegler, J.D., DOE. "Transmittal of Report Addressing Key Technical Issue (KTI) Agreement Item Unsaturated and Saturated Flow Under Isothermal Conditiions (USFIC) 3.02." Letter (November 22, 2002) to J. Schlueter, NRC.

engineered barrier performance assessment submodels and to associated detailed process models, will lead to a reassessment of Agreement TEF.2.13. Specifically, changes to the corrosion model parameters (e.g., chemistry of solutions contacting the waste package) or engineered barrier subsystems (e.g., drip shield and the Alloy 22 of the waste package) could cause the quantity and timing of water contacting the waste to become risk-significant.

In conclusion, additional risk information is needed to complete Agreement TEF.2.13 based upon risk assessments and sensitivity analyses.

5 SUMMARY

DOE presented both technical lines of evidence and risk information to support closure of Agreement TEF.2.13. The technical lines of evidence did not adequately address the concerns underlying Agreement TEF.2.13. Additional technical information needed to complete Agreement TEF.2.13 was presented. The risk information, while appearing to support closure, lacks the transparency and completeness requested by NRC[7]. Three suggested areas of improvement were presented, which are consistent with improvements suggested for submittals by DOE for other technical agreements intended to be addressed with a risk argument. Therefore, the NRC believes this agreement requires additional information.

6. STATUS OF AGREEMENT

The status of Agreement TEF.2.13 is “need additional information.” Additional technical information is needed if DOE chooses to complete Agreement TEF.2.13 based upon technical merit (see Section 4.1). Additional risk information is needed if DOE chooses to complete Agreement TEF.2.13 based upon risk assessments and sensitivity analyses (see Section 4.3).

7. REFERENCES

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