April 22, 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 TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI).3.23 (STATUS: COMPLETE) AND AGREEMENT GENERAL (GEN).1.01, COMMENT 18 (STATUS: COMPLETE), COMMENT 24 (STATUS: NOT RECEIVED), AND COMMENT 69 (STATUS: NOT RECEIVED)

Dear Mr. Ziegler:

In your letter dated January 21, 2003, the U.S. Department of Energy (DOE) enclosed a response to Agreement TSPAI.3.18, TSPAI.3.21, TSPAI.3.23, Thermal Effects on Flow (TEF).2.13, and GEN.1.01, Comments 18, 24, and 69. The January 21, 2003, letter transmitted the report titled, "Key Technical Issue Letter Report Response to TSPAI.3.18, TSPAI.3.21, TSPAI.3.23, and TEF.2.13." This 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 Agreements TSPAI.3.23 and GEN.1.01, Comments 18, 24, and 69, and the results of the staff's review are enclosed. Separate NRC review letters are in preparation for Agreements TSPAI.3.18, TSPAI.3.21, and TEF.2.13.

Agreement TSPAI.3.23 states that DOE will evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts, and transport. Regarding Agreement TSPAI.3.23, the staff's concerns involving heterogeneity in the unsaturated zone at Yucca Mountain can be logically divided into three areas: (1) effects of heterogeneity within the Paintbrush nonwelded tuff (PTn) unit on the attenuation of episodic infiltration and lateral redistribution of deep percolation; (2) effects of heterogeneity on the formation of focused flow paths reaching the proposed repository horizon; and (3) effects of heterogeneity on the formation of rapid transport pathways below the proposed repository horizon. The technical content and references in the report provided the staff with a sufficient understanding of the potential effects of heterogeneity on unsaturated flow and drift seepage at Yucca Mountain, and of how these processes are accounted for in DOE performance assessment analyses. Agreement TSPAI.3.23 is therefore considered complete.

The DOE report also provided results from dose-based, sensitivity studies in order to demonstrate that the current understanding of heterogeneity 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 TSPAI.3.23 on the basis of low risk significance. 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.

Agreement GEN.1.01, Comment 18 questions the differences in the results of two model seepage studies. Comment 18 is considered complete based on the staff’s understanding that the seepage parameters chosen for modeling of heterogeneity effects on in-drift temperature and humidity were conservatively chosen as extreme cases for the purpose of that analysis and were not intended to be representative.

DOE has suggested that comment 24 (PTn acts as capillary barrier), and comment 69 (significant lateral flow) of Agreement GEN.1.01 would be more appropriately addressed in conjunction with the response to Agreement USFIC.4.04, which requests DOE to provide justification for the ability of the PTn geologic unit to attenuate episodic infiltration. This suggestion is acceptable to NRC staff. The status of both comments is “not received.”

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 TSPAI.3.23 and Agreement GEN.1.01, Comments 18, 24, and 69.

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Letter to J. Ziegler from J. Schlueter dated: April 22, 2003
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NRC On-Site Representatives

supported the completion of Agreement TSPAI.3.23 on the basis of low risk significance. 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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Sincerely,
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Janet R. Schlueter, Chief
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Office of Nuclear Material Safety
and Safeguards

Attachment: NRC Review of DOE Documents Pertaining to Key Technical Issue Agreement TSPAI.3.23 and Agreement GEN.1.01, Comments 18, 24, and 69.

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NRC Review of DOE Documents Pertaining to
Key Technical Issue Agreements TSPAI.3.23 and GEN.1.01, Comments 18, 24, and 69

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 review of a license application. Just as important, resolution by the NRC staff during pre-licensing does not prejudge what the NRC staff evaluation of that issue will be after a 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 Total-System Performance Assessment and Integration (TSPAI) 3.23[1] and KTI Agreement General (GEN), Comments 18, 24, and 69[2]. These agreement are addressed by DOE in a letter[3] and attached report (Rickertsen, 2003), which are the subject of this review.

1 Wording of the Agreements

TSPAI.3.23: "DOE should evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts and transport. DOE should also provide a technical basis for the assessment that bomb-pulse Cl-36 data found below the Paint Brush tuff can be linked to a negligible amount of fast flowing water. DOE will evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts and transport. This evaluation will be documented in the Unsaturated Zone (UZ) Flow Models and Submodels Analysis Model Report (AMR) (MDL-NBS-HS-000006), Radionuclide Transport Models under Ambient Conditions (MDL-NBS-HS-000008) and Seepage Models for Performance Assessment (PA) Including Drift Collapse AMR (MDL-NBS-HS-000002) expected to be available to NRC in FY 2003. DOE will also provide a technical basis for the assessment that bomb-pulse Cl-36 data found below the Paintbrush nonwelded tuff (PTn) can be linked to a negligible amount of fast flowing water. The technical basis will be documented in the UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006) expected to be available to NRC in FY 2003."

GEN.1.01: "For NRC comments 3, 5, 8, 9, 10, 12, 13, 15, 16, 18, 21, 24, 27, 36, 37, 41, 42, 45, 46, 50, 56, 64, 69, 75, 78, 81, 82, 83, 93, 95, 96, 97, 98, 102, 103, 104, 106, 109, 110, 111, 113, 116, 118, 119, 120, 122, 123, 124, and 126, DOE will address the concern in the documentation for the specific KTI agreement identified in the DOE response (Attachment 2). The schedule and document source will be the same as the specific KTI agreement."

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1 Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10, 2001)." Letter (August 23) to S. Brocoum, DOE.

2 Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Range of Operating Temperatures (September 18-19, 2001)." Letter (October 2, 2001) to S. Brocoum, DOE.

3 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.

GEN.1.01, Comment 18: "Results of seepage into drifts shown in Table 5.3.1.4.2-2 after return to ambient conditions appear to be significantly different than the results for the Seepage Model for PA Including Drift Collapse AMR and seepage abstraction. What is the reason for these differences and how will the seepage abstraction incorporate this model predicted range of variability?"

GEN.1.01, Comment 24: "No data to support the conclusion that sub layers in the PTn might act as capillary barriers."

GEN.1.01, Comment 69: "The alternative modeling of flow through the PTn as discussed on p. 3-25 is based on capillary pressure data of a single borehole. It seems that the conclusions use the implicit assumption that this single borehole (point) data is valid across the entire PTn layer. Spatial variability of this capillary pressure distribution could lead to very different modeling results. In particular, unless the spatial distribution of capillary pressures is supported, the strong lateral flow component and resulting damping function of the PTn is not supported. On the contrary, lateral flow could be limited in scale and result in localized flow focusing. The conclusion in section 3.3.3.5 on p 3-27 that the TSPA abstraction is conservative is not supported. It is only conservative with respect to the presented simulation including lateral PTn flow over the entire layer. It could be non-conservative if lateral flow were found to be spatially limited, thus leading to a flow focusing within the PTn layer."

Note: references to tables, page numbers, and report sections in the preceding GEN.1.01 comments pertain to the Supplemental Science and Performance Assessment document (Bechtel SAIC Company, 2001).

2 Background

The staff reviews of heterogeneity in the unsaturated zone at Yucca Mountain can be logically divided into three areas: (1) effects of heterogeneity within the PTn unit on the attenuation of episodic infiltration and lateral redistribution of deep percolation; (2) effects of heterogeneity on the formation of focused flow paths reaching the proposed repository horizon; and (3) effects of heterogeneity on the formation of rapid transport pathways below the proposed repository horizon.

The relatively high matrix permeability and moisture retention capacity of the PTn unit, combined with its relatively low fracture density, make this geologic layer ideally suited to reduce the temporal variability of surface infiltration. The attenuation of episodic flow afforded by the PTn unit is the basis for the DOE modeling assumption that infiltration, drift-seepage, and unsaturated zone flow and transport can be treated as steady-state processes. The presence of bomb-pulse chlorine-36 detected below the PTn, however, may indicate the presence of some fast flow paths though the PTn. It is, therefore, necessary to evaluate the role of heterogeneity in the PTn unit on the possible occurrence of episodic flow and the formation of fast flow pathways, which could result in increased amounts of seepage into repository drifts at some locations.

Heterogeneity of the PTn unit could also affect the potential for lateral flow diversion along capillary or permeability barriers that might form at interfaces of sublayers within the PTn. Bechtel SAIC Company (2001, Section 3.3.3), for example, provided results from a site-scale unsaturated flow model that used a more refined computational grid than the model used in total-system performance assessments. The results of the refined-grid model suggest that the formation of capillary barriers along the gently-dipping hydrostratigraphic layer interfaces can cause downward percolating water to be diverted laterally toward fault zones or away from the area overlying the repository. Such lateral diversion of flow away from the repository footprint could be beneficial to repository performance. The staff is concerned that the refined-grid model did not include heterogeneity of matrix permeability or moisture retention parameters in the PTn unit, nor did it include the effects of fractures and uneven layer interfaces, all of which would act to limit lateral flow along layer interfaces (Fedors et al., 2002). The concern that heterogeneity is not appropriately considered in the refined-grid model formed the basis for both comments 24 and 69 of Agreement GEN.1.01.

Below the PTn unit, flow in the Topopah Spring welded tuff (TSw) geologic unit is believed to occur mainly in fracture networks. Fracture network heterogeneity may result in the formation of focused or preferential flow pathways that could also lead to increased seepage into drifts at some locations, when compared to a case with a uniformly distributed deep percolation flux. The DOE seepage model for performance assessment (CRWMS M&O, 2000b) does explicitly include heterogeneity in its representation of the fracture network as a three-dimensional equivalent porous continuum. However, the seepage model was developed using an assumption of uniformly distributed percolation flux at the top boundary of the seepage model. At the time Agreement TSPAI.3.23 was reached, it was not clear how seepage model results might differ if focused infiltration points were considered for the top model boundary.

Below the repository horizon, focused or preferential flow pathways in the TSw and the underlying Calico Hills non-welded tuff formation could accelerate transport of contaminants to the saturated zone in the event of a radionuclide release from the proposed repository. The DOE site-scale unsaturated zone flow model for Yucca Mountain explicitly includes larger-scale heterogeneity in the Calico Hills formation by dividing this layer into two hydrostratigraphic material types to represent both vitric and zeolitically altered nonwelded volcanic tuff. This approach is generally consistent with available data and the DOE model does reproduce the observed presence of perched water bodies above zeolitically altered Calico Hills tuff in the northern area of the proposed repository (CRWMS M&O, 2000a). The DOE model also includes discrete fault zones as another form of heterogeneity below the repository horizon. The DOE model results suggest that much of the perched water that forms above the zeolitized Calico Hills tuff is diverted laterally toward fault zones where it moves relatively rapidly toward the water table.

3 NRC Review

The Rickertsen (2003) report provides three areas of discussion to support the completion of key technical issue Agreement TSPAI.3.23. 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.

3.1 Review of Technical Information and Associated References

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

In reference to hydrostratigraphic units between the ground surface and the proposed repository horizon, the Rickertsen (2003) report states that "spatial heterogeneity within hydrostratigraphic units is unimportant to the distribution of vertical flux, because these units have vertical unsaturated hydraulic conductivity that is in excess of that needed to support free drainage." Staff agree that this statement is generally true for average hydrologic properties at the scale of the unsaturated flow model numerical grid blocks. At sub-grid-block scales of a few tens of meters of less, however, focused flow paths caused by local heterogeneities probably do occur. A recent modeling study by Bechtel SAIC Company (2001, Sections 4.3.2.4 and 4.3.2.5), for example, suggests that heterogeneity in the TSw unit can produce preferential flow paths with spacings that are a function of the correlation length scale for heterogeneity.

Another important result of the Bechtel SAIC Company (2001) heterogenous flow model is that, when preferential flow paths reach a new hydrostratigraphic layer, the flow paths tend to be redistributed quickly (within a few correlation lengths) according to the degree of heterogeneity in the new layer. This latter result was achieved both for uniformly distributed flux input at the top of rock layers and for flux input focused at intermittent locations. Independent modeling by Fedors, et al. (2002) produced similar results. The results of the heterogenous flow model studies are not cited in the Rickertsen (2003) report, but are worth mentioning because they address the staff concern regarding whether seepage model results might differ if a focused flux boundary, rather than a uniform flux boundary, were to be applied at the top of the model domain. The results of the Bechtel SAIC Company (2001) heterogenous model suggest that seepage model results should not differ significantly with a focused flux boundary. The distance between the top model boundary and the drift-crown interface in the DOE seepage model (CRWMS M&O, 2000b) is about 10 m (33 ft). Because this distance comprises several correlation lengths, there is ample time for flow to be redistributed according to the heterogeneity in the seepage model, regardless of whether the top infiltration boundary is uniform or contains discrete infiltration points. Note that heterogeneity correlation lengths of 0.5 m, 1.0 m, and 4.0 m (1.6 ft, 3.3 ft, and 13.1 ft) were evaluated in DOE seepage modeling analyses (CRWMS M&O, 2000b).

The Rickertsen (2003) report points out that potential for flow focusing caused by heterogeneity above the potential repository horizon is also accounted for by using a flow focusing factor that varies stochastically from a value of 1 to an upper limit value ranging between 9.7 or 47, depending on the representation of net infiltration. 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, 2000c). The Bechtel SAIC Company (2001) model of heterogenous unsaturated zone flow, although not cited in the Rickertsen report, generally supports the conclusion that this representation of flow focusing provides a reasonable approach for including the effects of heterogeneity above the repository horizon.

For transport pathways below the potential repository horizon, the Rickertsen (2003) report explains that heterogeneity in the spatial distribution of vitric and zeolitic rocks within the Calico Hills unit is explicitly included in the DOE site-scale unsaturated flow model. Cores from boreholes within the site-scale model domain were used to define vitric and zeolitic zones in the site-scale model grid. The calibrated site scale model generally matches observations of perched water above zeolitic zones in the northern model area. DOE transport model results suggest flow above the low-permeability zeolitic zones flows laterally toward fault zones where it then moves quickly downward to the saturated zone (CRWMS M&O, 2000a).

Bechtel SAIC Company (2003, Section 5.3.1.4.2) conducted modeling analyses to evaluate the effects of increased drift seepage caused by heterogeneity on in-drift temperature and humidity estimates. In those modeling analyses, the estimated percentages of flow that seeps into drifts following the thermal period, were substantially greater than the seepage estimates developed in the performance assessment for the Site Recommendation (CRWMS M&O, 2000b). The difference in seepage estimates obtained from the two modeling activities formed the basis for the staff's request for additional information in comment 18 of Agreement GEN.1.01. Upon further review of the Bechtel SAIC Company (2003, Section 5.3.1.4.2) modeling analyses, it is clear that the seepage model parameters chosen for that study were purposely chosen as extreme examples that would result in excess drift seepage so that the effects of seepage heterogeneity on in-drift temperature and humidity could be evaluated.

3.2 Review of the Physical Relationship of the Unsaturated Flow System on Barrier Capabilities of the Proposed Repository

The role of unsaturated zone heterogeneity on the barrier capabilities of the proposed repository system is also discussed in the Rickertsen (2003) report. 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. The evaluation of 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 part of the key technical issue Agreements ENFE.2.06 and ENFE.2.09. Additional confidence will be provided for conclusions stating that increased seepage would have either minimal or beneficial effects on corrosion rates upon the successful completion of such agreements which increase the understanding of the potential range of local chemical conditions that may occur on drip shield and waste package surfaces.

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. Rickertsen (2003) provides dose-based sensitivity analyses to 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

The total-system sensitivity analyses described by Rickertsen (2003) include three types of analyses: (1) a comparison of mean dose estimates between a case where the base-case net infiltration is used and a case where net infiltration is set to an bounding 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). The three types of sensitivity analyses are completed for two scenarios [Rickertsen (2003)]: 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.

For the nominal scenario, results indicate that dose estimates are marginally higher for the bounding net infiltration case compared to the base case; the increased mean annual dose is approximately 10 percent. The lack of sensitivity of the nominal case to the net infiltration 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. Increased infiltration would result in increased wetting of the drift invert, which accommodates slightly higher diffusive release rates. Increased infiltration 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 Rickertsen (2003) report. Transparency and completeness in the description of the implementation of the bounding net infiltration case for the nominal scenario supports the risk-based argument.

Sensitivity of mean dose estimates to net infiltration 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 (2002) indicates that the timing of the igneous event is stochastically sampled over the 100,000 year simulation period. The dose estimates for the bounding infiltration case are about two to three times as great as the dose estimates using the base-case infiltration rates in the igneous activity scenario. The sensitivity study presented in the DOE report explains that the increased dose estimates for the igneous groundwater scenario and the increased sensitivity to bounding infiltration (compared to the nominal case) are the result of the breached drip shields and waste packages, which permit advective flow to contact the waste.

The infiltration sensitivity study includes the far field effect of increased infiltration, but does not include near-field effects such as increased seepage into emplacement drifts. The seepage sensitivity study addresses the effects of increased seepage that may be associated with higher infiltration. For both the bounding infiltration and seepage sensitivity analyses, the results of the nominal scenario analyses suggest mean annual dose estimates are dominated by highly soluble radionuclides and, because the inventory of these radionuclides can be exhausted by relatively small amounts of water, the results are not very sensitive to increased infiltration or seepsge.

For the igneous activity groundwater release scenarios of bounding infiltration and seepage, dose estimates are also influenced by some less soluble radionuclides, and therefore the amount of water contacting the waste is shown to have a more significant effect on dose than it does in the nominal case. The increase in mean annual dose estimates for the bounding cases was generally less than an order of magnitude above the expected case dose estimates, however, and generally less than about 0.001 mSv (0.1 mrem) during the 10,000 yr compliance period, which is substantially below the 0.15 mSv (15 mrem) regulatory limit.

For the sensitivity analyses of complete neutralization of flow and transport, mean doses for the 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 base case dose estimates, the peak doses remained significantly below the 15 mrem regulatory limit during the 10,000 yr 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

Heterogeneities explicitly included in the DOE site-scale unsaturated zone model include the designation of hydrogeologic units to account for geologic units (or groups of subunits) with different hydrologic properties, the inclusion of certain faults as separate hydrogeologic features, the inclusion of layer offsets associated with fault zones, and the division of the Calico Hills unit into vitric and zeolitic zones. Intra-layer heterogeneities are not considered for other hydrogeologic units other than the Calico Hills unit.

4.1 Comments and Conclusions on the Technical Information and Associated References

As explained in the Rickertsen (2003) report, the explicit inclusion of faults in the unsaturated flow model causes model results to show a small fraction of infiltrating water moving relatively quickly through the PTn unit at fault locations, which is consistent with the observation that bomb-pulse chlorine-36 previously found below the PTn unit is generally associated with faults or intensely fractured zones.

The assumption of a homogenous PTn unit in the DOE unsaturated flow model does not produce significant lateral spreading of spatially variable infiltration, as evidenced from a comparison of model results of the spatial distribution of flow reaching the repository horizon to the spatial distribution of surface infiltration at the top model boundary (CRWMS M&O, 2000a). Thus, modeled flow through the PTn layer is predominantly vertical and gravity driven because, at the model grid-block scale, the permeability of the PTn layer is high enough to accommodate the input infiltration flux. Heterogeneity in the PTn unit at the sub-grid-block scale could produce smaller scale focused flow pathways. However, the results of the two-dimensional heterogenous flow model by Bechtel SAIC Company (2001) show that small-scale variability of flow at the base of the PTn layer is generally irrelevant because flow leaving the base of the PTn is quickly redistributed according to the heterogeneity in the underlying TSw unit.

The information provided by Rickertsen (2003) does not address the potential effects of heterogeneity on the efficacy of the PTn unit for attenuating episodic infiltration to an essentially steady-state flow system below the PTn unit, as is assumed in the DOE unsaturated zone flow model. The staff concern that the steady-state flow assumption needs additional justification is being addressed separately, however, as agreed by DOE in key technical issue Agreement USFIC.4.04.

DOE has suggested that comment 24 (PTn acts as capillary barrier), and comment 69 (significant lateral flow) of Agreement GEN.1.01 would be more appropriately addressed in conjunction with the response to Agreement USFIC.4.04, which requests DOE to provide justification for the ability of the PTn geologic unit to attenuate episodic infiltration. This suggestion is acceptable to NRC staff.

Comment 18 of Agreement GEN.1.01 can also be considered complete based on the staff's understanding that the seepage parameters chosen for the Bechtel SAIC Company (2001, Section 5.3.1.4.2) of modeling of heterogeneity effects on in-drift temperature and humidity were conservatively chosen as extreme cases for the purpose of that analysis and were not intended to be representative.

Although heterogeneity in the TSw unit is not explicitly included in the DOE unsaturated flow model, it is taken into account for the seepage abstraction through the use of a flow focusing factor. The Bechtel SAIC Company (2001) analyses indicate that the selected parameter values for the flow focusing factor are conservatively selected. The results of the Bechtel SAIC Company (2001) heterogenous model also suggest that seepage model results should not differ significantly with a focused flux boundary, given the fracture continuum heterogeneity correlation lengths of 0.5, 1.0 m, and 4.0 m (1.6 ft, 3.3 ft, and 13.1 ft) that were considered in the DOE seepage analyses. Note that, for the purpose of estimating drift seepage, the question remains as to whether it is a valid conceptual approach to treat a fracture network as a uniform continuum in which heterogeneity is assumed to be a random, spatially correlated parameter. This open question, however, is addressed by agreement items USFIC.4.06, which request DOE to provide a comparison of continuum and discrete fracture models or otherwise justify the continuum approach at the scale of the seepage model grid.

Below the proposed repository horizon, the effects of heterogeneity on transport pathways in the TSw unit are accounted for in the DOE unsaturated zone transport model by using the "active fracture" concept of Liu, et al. (1998) to increase flow velocities and to reduce the fracture-matrix interface area available for matrix diffusion. In general, the use of the active fracture concept to account for the effects of focused flow paths in the unsaturated zone transport model is a reasonable approach for including heterogeneous flow paths in the transport model abstraction. Although it is not yet clear to staff that the active fracture conceptual model and parameter estimates are properly implemented in the transport model abstraction, that particular concern is being addressed under separate key technical issue agreements (e.g., TSPAI.3.28 and TSPAI.3.29).

4.2 Comments and Conclusions on the Sensitivity Analyses for Risk Importance

The sensitivity analyses provided by Rickertsen (2003) provide useful insight into the risk importance of seepage and flow in the unsaturated zone. However, three areas of information are missing from these sensitivity analyses. 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, only the mean results of the stochastic performance assessment simulations are presented. Some measure of how the variability of results changes between the different modeled cases is needed. 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. NRC staff have previously commented to DOE by letter [4] regarding additional

4 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.

information that is needed when using risk as a basis to complete key technical issue agreements. 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 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 analyses 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 TSPA model.

   An adequate description of what changes were made to the model for the analyses is needed. Some example of questions/comments in this regards are given below.

   - The Rickertsen (2003) report states that the model for the igneous activity groundwater release scenario assumes that magma "damages" a number of waste packages and drip shields. The number is a probability distribution that average 300. What is the level of damage represented within this number?

   - The rationale for the bounding seepage value ($1 m^3/yr$) 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 $1 m^3/yr$ 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 attached DOE report[5] 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 infiltration analysis is quite pessimistic compared to the data provided in Figure 1.

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5 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.

- Figure 3 (a and b) show the results of sensitivity studies in which natural barrier transport parameters are neutralized and also a case where both flow and transport parameters are neutralized. No difference in arrival times of the earliest doses between the two sensitivity case studies is discernible in these figures. Is there any time lag in dose arrival time afforded by the inclusion of the natural barrier flow parameters?

- 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 TSPAI.3.23 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 5^{th} and 95^{th} 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.

5 Status of Agreement

Although the DOE sensitivity analyses would require some additional information to complete Agreement TSPAI.3.23, the technical content and references in the report by Rickertsen (2003), combined with other analyses on the affects of heterogeneity on unsaturated flow (i.e., Bechtel SAIC Company, 2001), do provide the staff with a sufficient understanding of the potential effects of heterogeneity on unsaturated flow and drift seepage at Yucca Mountain, and of how these processes are accounted for in DOE performance assessment analyses. Remaining concerns related to the treatment of unsaturated zone heterogeneity are addressed by other key technical issue agreements, as discussed in the preceding review. Staff therefore consider Agreement TSPAI.3.23 to be complete based on available information.

Comment 18 of Agreement GEN.1.01 is also considered complete. Comments 24 and 69 of Agreement GEN.1.01 have the status “not received” and will be addressed by DOE in conjunction with Agreement USFIC.4.04.

6 References

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