February 26, 2003

Joseph D. Ziegler, Acting Director
Office of License Application and Strategy
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Office of Repository Development
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SUBJECT: THE U.S. NUCLEAR REGULATORY COMMISSION REVIEW OF THE U.S. DEPARTMENT OF ENERGY DOCUMENTS PERTAINING TO AGREEMENT UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS (USFIC).3.02 (STATUS: ADDITIONAL INFORMATION NEEDS) AND AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI).3.22 (STATUS: ADDITIONAL INFORMATION NEEDS)

Dear Mr. Ziegler:

In your letters dated August 29, 2002, and November 22, 2002, the U.S. Department of Energy (DOE) enclosed a response to Agreement TSPAI.3.22 and Agreement USFIC.3.02, respectively. This letter serves to clarify the U.S. Nuclear Regulatory Commission (NRC) staff's review of the DOE submittals and identifies additional information needs.

Agreement USFIC.3.02 states that DOE will provide justification for certain infiltration uncertainty parameters and document the Alcove 1 and Pagany Wash tests. The November 22, 2002, letter transmitted the report titled, "Response to USFIC.3.02: Justification of Parameters Used in the Infiltration Uncertainty Analysis," documenting the technical bases for the entries in Table 4-1 of CRWMS (2000c), data from the Alcove 1 and the Pagany Wash tests, and a Total System Performance Assessment (TSPA) sensitivity study on net infiltration. The NRC staff has reviewed this information, with respect to Agreement USFIC.3.02, and the results of the staff's review are enclosed.

The staff's concern reflected in key technical issue Agreement USFIC.3.02 was that it is not clear whether hydrologic parameter uncertainty has been adequately incorporated in the parameter distributions used in the development of the stochastic weighting for the three infiltration cases. The justification and technical bases for the hydrologic "uncertain input parameter distribution for the glacial transition climate" state (i.e., Table 4-1 of CRWMS (2000c)) is inadequate, particularly the shifts in ranges that cause a reduction in net infiltration.

Documentation of large-scale tests relevant to net infiltration at Yucca Mountain was requested in key technical issue Agreement USFIC.3.02. DOE has provided insufficient documentation and analyses of aspects of the Alcove 1 infiltration test. However, LeCain et al. (2002) adequately documents the Pagany Wash test.

In addition to providing partial technical bases for the parameters in Table 4-1 of CRWMS (2000c) and information on the Alcove 1 and Pagany Wash tests, the DOE report provided results from a dose-based, sensitivity study. DOE hopes to demonstrate that the current understanding of the infiltration model 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 study provided is not sufficiently documented to support the completion of Agreement USFIC.3.02 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. It is expected that the following information would be presented: (i) combined effect of uncertainty associated with agreements addressed with risk information; (ii) transparency of changes made to implement the sensitivity analyses and explanation of the results; and (iii) details on the distribution of simulation results.

In summary, DOE can choose to complete Agreement USFIC.3.02 by one of two ways: 1) provide sufficient justification and technical bases for the hydrologic "uncertain input parameter distribution for the glacial transition climate" state, or 2) provide sufficient and adequate risk information as discussed in the January 27, 2003, risk letter.

Agreement TSPAI.3.22 states that DOE will provide an assessment or discussion of the uncertainty involved with using a hydrologic property set obtained by calibrating a model on current climate conditions and using that model to forecast flow for future climate conditions. The August 29, 2002, letter transmitted the report entitled "Response to TSPAI.3.22, Representation of Unsaturated Zone Flow" documenting a TSPA sensitivity study on net infiltration, and on natural barrier flow and transport parameters. The NRC staff has reviewed this information, with respect to Agreement TSPAI.3.22, and the results of the staff's review are enclosed.

DOE's report responding to TSPAI.3.22 contains no technical bases to complete this agreement. Instead, DOE has provided the results of a TSPA sensitivity study and hopes to demonstrate that the representation of uncertainty in either the amount of water or the details of the description of its movement through the UZ does not play a significant role in determining whether the postclosure performance objectives of 10 CFR Part 63 would be met. Based on the guidance on the use of risk information to complete agreements as provided by NRC in its letter to DOE dated January 27, 2003, the risk sensitivity study provided is not sufficiently documented to support the completion of Agreement TSPAI.3.22 on the basis of low risk significance. DOE needs to provide sufficient and adequate risk information as discussed in the January 27, 2003, risk letter.

The ultimate disposition of Agreements USFIC 3.01 and TSPAI.3.22 will be determined after DOE adequately addresses NRC's concerns with its approach to resolving agreements via risk arguments. 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.

Additional information as described in the attachment is needed to complete the key technical issue Agreement USFIC.3.02 and Agreement TSPAI.3.22. 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 USFIC.3.02 and Agreement TSPAI.3.22

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Letter to J. Ziegler from J. Schlueter dated: February 26, 2003
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Additional information as described in the attachment is needed to complete the key technical issue Agreement USFIC.3.02 and Agreement TSPAI.3.22. 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 USFIC.3.02 and Agreement TSPAI.3.22

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NRC Review of DOE Documents Pertaining to Key Technical Issue Agreements USFIC.3.02 and TSPAI.3.22

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 Agreement Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC).3.02[1] and key technical issue Agreement Total System Performance Assessment and Integration (TSPAI).3.22.[2]

1 Agreement USFIC.3.02

1.1 Wording of the Agreement

USFIC.3.02 states: "Provide justification for the parameters in Table 4-1 of the Analysis of Infiltration Uncertainty AMR (for example, bedrock permeability in the infiltration model needs to be reconciled with the Alcove 1 results/observations). Also, provide documentation (source, locations, tests, test results) for the Alcove 1 and Pagany Wash tests. DOE will provide justification and documentation in a Monte Carlo analyses document. The information will be available in February 2002."

1.2 Background

Previous DOE sensitivity analyses have stated that infiltration is the quantity that has the greatest impact on UZ flow and transport (CRWMS, 2000d). The shallow infiltration subissue of the Unsaturated and Saturated Flow Under Isothermal Conditions key technical issue was previously considered resolved at the NRC staff level following the publication by DOE of the total system performance assessment performed for the Viability Assessment (U.S. Department of Energy, 1998). The resolution of this subissue was based, in part, on staff's conclusion that the upper-bound net infiltration rates for present and future climates considered in the DOE abstraction reasonably bounded the uncertainty in net infiltration at Yucca Mountain. DOE subsequently refined their net infiltration model, and estimates of net infiltration above the potential repository were revised to lower values. For example, the upper-bound case for present-day annual infiltration used for the Viability Assessment (U.S. Department of Energy,

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[1]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Unsaturated and Saturated Flow Under Isothermal Conditions (October 31–November 2, 2000)." Letter (November 17, 2000) to S. Brocoum, DOE.

[2]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.

ATTACHMENT

1998) yielded a spatial average of 23 mm/yr [0.91 in/yr] over the proposed repository area (CRWMS M&O, 1998). This upper bound estimate was reduced to 11.6 mm/yr [0.46 in/yr] in the analyses used to support the site recommendation (CRWMS M&O, 2000a, b). The revised net infiltration estimates prompted staff to reexamine the shallow infiltration subissue. In the Yucca Mountain Program, the term "shallow infiltration" has generally been replaced by the term "net infiltration," a usage that will be followed in the remainder of this document.

During the reexamination of the net infiltration model results, staff identified several issues regarding data and the information used to constrain the net infiltration model results, specifically: (i) the interpretation of chloride mass balance results for a fractured tuff environment, including assumptions pertaining to precipitation chemistry, matrix-fracture equilibrium, and the origin and conceptual model of flow for the perched water body; (ii) the use of secondary mineralization to predict expected net infiltration, even when the key assumption of secondary mineralization reflecting percolation pathways is in conflict with another DOE model (seepage model and conceptualization of seepage threshold would generally preclude flow into lithophysae); (iii) the higher net infiltration rates estimated using temperature profiles; (iv) the assumption that neutron probe data in fractured bedrock reflects both matrix and fracture flow; and (v) the relevance of an empirical regional water budget approach (i.e., Maxey-Eakin) that was developed using primarily alluvial basin when applied to upland areas, such as the repository footprint on Yucca Mountain, where thin soils are prominent. To address the concern over the magnitude of net infiltration estimates, NRC staff focused on evaluating whether uncertainty in the estimates was adequately considered for the purpose of performance assessment modeling.

Uncertainty in net infiltration is incorporated in the DOE total system performance assessment (CRWMS M&O, 2000a) in three steps. First, lower-bound, mean, and upper-bound estimates of net infiltration are derived for the modern, monsoonal, and glacial-transition climates using selected climatic (precipitation and air temperature) data sets. Hence, uncertainty in climate data used as a boundary condition for the infiltration model is addressed in the first step. The second step uses parameter uncertainty to determine the stochastic weighting of lower-bound, mean, and upper-bound net infiltration cases. The stochastic weighting refers to the probability that a particular case (lower-bound, mean, or upper-bound) will be selected for any individual realization of the DOE total-system performance assessment. These stochastic weights for the three net infiltration estimates were derived by DOE from a Monte Carlo type of analysis using Latin-Hypercube sampling from distributions of uncertain parameters (CRWMS M&O, 2000c). The results of the multiple Monte Carlo simulations were used to estimate the range of uncertainty in infiltration estimates for the glacial-transition climate scenario. The resulting distribution of infiltration estimates was used to estimate the stochastic weight to be assigned to the three infiltration cases used in performance assessment modeling. Table 4-1 of CRWMS (2000c) contains the mean and range for twelve parameters used to describe the distributions sampled by the Latin-Hypercube algorithm. Ten of the twelve parameters in Table 4-1 of CRWMS (2000c) apply to the modern and monsoonal climates. The third step is to stochastically select one of three different net infiltration cases for each performance assessment realization, and use the weighting scheme to constrain the distribution of net infiltration cases selected for the ensemble of realizations. Key technical issue Agreement USFIC.3.02 was reached to address a concern raised by staff in the second step for incorporating uncertainty in the DOE net infiltration abstraction.

The staff concern reflected in key technical issue Agreement USFIC.3.02 was that it is not clear whether hydrologic parameter uncertainty has been adequately incorporated in the parameter distributions used in the development of the stochastic weighting for the three infiltration cases. In particular, NRC staff requested that a supporting basis be provided for the mean values and ranges for the twelve uncertain parameters in Table 4-1 of CRWMS (2000c). A corrected version of Table 4-1 of CRWMS (2000c) was discussed at the technical exchange and management meeting[3], however, no supporting bases for the means and ranges were provided. In addition, large-scale tests at Alcove 1 and Pagany Wash had not been documented. It was believed that this information could potentially be used to evaluate or support the net infiltration model. Thus, documentation was requested as part of the USFIC.3.02 agreement.

1.3 NRC Review

In response to key technical issue USFIC.3.02, DOE provided a letter[4] and accompanying technical report, herein referred to as the DOE report. Section 3.1 of the DOE report discusses the technical bases for the entries in Table 4-1 of CRWMS (2000c). Section 3.2 discusses data from the Alcove 1 and the Pagany Wash tests. Section 3.3 discusses sensitivity analyses intended to demonstrate that further technical justification is not warranted based on a low risk significance of net infiltration to system performance. The review of this DOE report is divided accordingly into the three sections below.

In the DOE report, it was noted that "during the preparation of this response, typographical errors were identified" in Table 4-1 of CRWMS (2000c). These typographical errors were brought to DOE's attention prior to the November 2000 technical exchange and management meeting,[5] and staff were provided a corrected table prior to the technical exchange and management meeting. Deficiency Report BSC(B)-02-D-144 was issued to track the corrections to Table 4-1 of CRWMS (2000c) and ensure that a basis for the mean and range is provided in the revision to CRWMS (2000b).

1.3.1 Table 4-1 of CRWMS (2000c)

Table 4-1 of CRWMS (2000c) contains the mean, minimum, and maximum values for the twelve net infiltration parameters used to determine the stochastic weights for the performance assessment Latin-Hypercube sampling for the glacial transition climate. Except for the uniformly distributed snow submodule parameters, the minimum and maximum are at the 1st and 99th percentile of the specified normal or log-normal distributions. The minimum and maximum values will be referred to as the range in the remainder of this review. Correlation of parameters is considered by DOE. Parameter distributions for the modern and monsoonal climates were not

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[3]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Unsaturated and Saturated Flow Under Isothermal Conditions (October 31–November 2, 2000)." Letter (November 17, 2000) to S. Brocoum, DOE.

[4]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.

[5]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Unsaturated and Saturated Flow Under Isothermal Conditions (October 31–November 2, 2000)." Letter (November 17, 2000) to S. Brocoum, DOE.

presented in CRWMS (2000c).

1.3.1.1 DOE Bases for Table 4-1 of CRWMS (2000c)

The DOE report provided the original version of Table 4-1 of CRWMS (2000c) as table 1A. A corrected version, Table 1B in the DOE report, contains the corrected model parameter mean and range of values for the glacial-transition climate. Table 3 presented the mean and range of values sampled for the modern climate. The table of values for the modern climate was not previously available. No table of parameter distributions for the monsoonal climate were presented because parameter distributions from the modern climate were also applied to the short monsoonal climate period. NRC concurs that changes to parameter distributions for the monsoonal climate are not warranted. Tables of parameter distributions for the modern and glacial transition climate are discussed in detail below.

The mean values for the modern climate in Table 3 of the DOE report are supported as a consequence of the calibration to modern climate data. The mean parameter values are based on a manual calibration that used streamflow data, a generated meteorological record, average conditions of soils and near-surface bedrock, and average net infiltration values constrained by supporting approaches. Based on the presented discussion, the range for most of the parameters for the modern climate appears to be reasonably bounding. The supporting basis for the range of precipitation multiplier value, however, is difficult to evaluate. Most of the uncertainty in precipitation and temperature caused by climate change is incorporated in the implementation of lower and upper bound climate boundary conditions. Some uncertainty in precipitation is also addressed by inclusion of the precipitation multiplier in Table 4-1 of CRWMS (2000c). This portion of uncertainty is said in the DOE report to arise from “limitations in the available climate records (period of record, location of data points) for representing modern climate conditions, [and] the empirical elevation-precipitation correlation.” The distribution of the precipitation multiplier is said in the DOE report to be “consistent with observed variability.” There is a lack of transparency regarding how the precipitation multiplier range was developed from observed variability.

The supporting bases for the glacial-transition model parameter uncertainty distributions are more problematic. The primary parameters adjusted for the calibration to modern climate are the thickness of the bedrock layer included in the root zone, the effective storage capacity of the bedrock layer, and the surface flow area. Bulk bedrock permeability and soil depth were maintained as known values in the infiltration model calibration. There are many other parameters in the net infiltration model. The manual calibration led to one solution, however, it was one of many possible solutions (CRWMS 2000b); i.e., it is non-unique. Similar results might have been achieved by using different combinations of calibration parameters or by allowing other uncertain parameters to vary. It is not so important that other calibration results could have been achieved, but rather that meaningful changes to those parameters can become problematic when a model calibrated to present-day conditions is to estimate infiltration for future climate conditions. It is thus desirable that parameter estimates and uncertainty distributions used for model calibration have an appropriate physical basis or technical justification beyond the simple fact that they provide a good model calibration.

Shifting parameter values for the glacial transition climate from those estimated for the modern climate, particularly in a direction that reduces net infiltration estimates, requires defensible technical bases. For the glacial-transition climate, the mean or the range of several parameters in Table 1B of the DOE report have changed notably from those used for the uncertainty of modern net infiltration. Specifically:

- The bulk bedrock permeability (BRPERM) range is reduced for future glacial transition climates. The only arguments presented were in support of the mean value; i.e., no arguments for changing the distribution of bulk bedrock permeability were presented. One argument introduces constraints based on Hortonian overland flow appears to be more suited for supporting soil permeability estimates. Saturation-induced overland flow dominates in areas of thin soil cover, such as over the repository footprint. Another argument noted that caliche forms in the bedrock fractures for the modern climate and that caliche-filled fractures have a lower permeability than open fractures. Observations at climate analog sites with thin soil covers over fractured bedrock (e.g., Rainer Mesa, Shoshone Mountain, Grapevine Mountains, 3-Springs Watershed) show that caliche becomes much less prominent in wetter environments. Thus, bulk bedrock permeability might be expected to increase, not decrease. Decreases in the bulk bedrock permeability would likely lead to decreases in net infiltration estimated for the repository footprint.

- The soil permeability (SOILPERM) range decreased for the glacial transition climate, but the mean value remained the same as for the modern climate. While the variability of soil permeability likely increases for wetter climates as soil profile development occurs, the mean values likely would shift to lower values for the wetter climates. It is not clear if the narrower range in soil depths leads to higher or lower net infiltration estimates for the thin soils in the repository footprint.

- For the bedrock root zone (BRZDEPTH) depth parameter, the range remains the same, but the mean and distribution are shifted to larger depths. This shift increases the water-holding capacity of the bedrock, which acts to reduce net infiltration. The supporting basis for reducing the bedrock root zone depth was the intuitive argument that plant roots will reach deeper for water under a glacial transition climate.

- The range of soil depths (SOILDEPM) sampled for the glacial transition climate is reduced from that of the modern climate. Since essentially the same argument is given for each climate, a clarification of why the range should be different for the two climates should be presented. During a stable period of a wetter climate, the soil depths may become more uniform across the repository footprint. Due to nonlinearities in net infiltration processes, it is possible that net infiltration estimates for the glacial climate would decrease with a narrowing of the range for soil depths.

- It was not clear if the range for the precipitation multiplier (PRECIPM) changed between the modern and glacial transition climate. The mean value of the multiplier appeared to remain constant. A comparison of tables 1B and 3 in the DOE report indicates that the range did not change, but the text in section 3.1.3 of the DOE report discusses the narrower range in precipitation multiplier used for the glacial transition climate compared to that used for the modern climate. The DOE report notes that the range of the precipitation multiplier was reduced for the glacial transition climate from that used for the modern climate to: (i) “improve the defensibility of weighting factors” developed for the

Site Recommendation; (ii) because the lower and upper bound climate scenarios account for long-term precipitation uncertainty; and (iii) the analog climate records consisted of longer records. Similar to comments on the value of the multiplier used for the modern climate, it is not transparent how the range for the precipitation multiplier for the glacial transition climate was determined from the variability of meteorologic records at the climate analog sites. Due to nonlinearities in net infiltration processes, it is possible that net infiltration estimates would decrease with a narrowing of the range for precipitation multiplier.

- The surface flow runoff area (FLAREA) mean value and range were reduced for the glacial transition climate. Conceptually, the surface flow runoff area is a fraction of one that varies spatially and temporally. The mean value applied to the entire watershed for the modern climate was obtained by calibration, and the range was estimated based on qualitative field observations. The arguments presented in the DOE report for reducing the surface flow runoff area for the glacial transition climate are not transparent. It is not clear if changing the mean and range of the surface flow area parameter will significantly affect net infiltration estimates.

1.3.1.2 Staff Review of Bases for Table 4-1 of CRWMS (2000c)

The basis for mean parameter values for the modern climate is primarily derived from the calibration process. Shifts of these mean parameter values for other climates are difficult to defend based solely on model calibration, because other combinations of parameter values may have also resulted in good model calibration. Hence, technical bases are needed for model mean parameter values and uncertainty distributions.

The arguments presented for the values of parameter ranges for the modern climate appear reasonable, except for that of the precipitation multiplier, which lacks transparency when considered with the lower and upper bound climate strategy. None of the changes to the parameter ranges for glacial transition climate were supported by a discussion of the technical bases (e.g., evidence from other climate analog sites). Part of the support for parameter ranges in Table 1B and Table 3 of the DOE report rely on the inferred notion that non-physical results would occur if ranges are not reasonably chosen. This model self-consistency was used as a justification for changing parameter distributions for the glacial transition climate. Transparency or clarification of the model self-consistency argument and basis are needed. Changes to the parameter ranges for glacial transition climate require defensible technical bases, particularly the shifts in range that cause a reduction in net infiltration. Climate analog sites with thin soil cover over fractured bedrocks like that of Yucca Mountain could provide data on spatial and temporal distribution of open fractures verses filled fractures. If the justification for parameter distributions is to be based on model self-consistency for the glacial transition climate, while constraining average net infiltration estimates to the values supported by field data (e.g., temperature, saturation, chloride, secondary minerals), then a more transparent discussion is needed.

1.3.2 Alcove 1 and Pagany Wash Tests

Documentation of large-scale tests relevant to net infiltration at Yucca Mountain was requested in key technical issue Agreement USFIC.3.02, specifically, "... (source, locations, tests, test results) for the Alcove 1 and Pagany Wash tests." The rationale was that these important tests had not been documented, thus, their utility in establishing a basis for the net infiltration, or any other model, was severely limited. In addition to estimating bulk bedrock permeability at the scale of the net infiltration model, the Alcove 1 test also provided useful information about flow paths and seepage for other models. For example, prominent structural control on flow in the fractured tuff above Alcove 1 was suggested by the tracer data (Flint, et al., 2000). Since chemical, hydrological, and thermal conditions in the Paintbrush and Topopah Springs Tuffs are used to constrain the net infiltration model, adequate understanding of how water flows through these units could be important for evaluating the model.

Monitoring at Pagany Wash during the El Nino winter of 1997-98 captured a significant infiltration event. Monitored borehole data from various depths within the alluvium, moderately welded Tiva Canyon units, nonwelded Paintbrush units, and welded upper Topopah Springs units could potentially lead to interpretations relevant to the net infiltration model. Preliminary work by LeCain, et al. (2000) had noted prominent differences in advancing percolation fronts between two boreholes. Borehole UZ#4 is sited on the toe of a hillslope near the edge of a wash where only a thin colluvial soil is present, and borehole UZ#5 is sited in the middle of Pagany Wash where approximately 12 m of alluvium was present. Previous analysis on data collected prior to 1997 from the same two boreholes (UZ#4 and UZ#5) had been used to support two-dimensional thermohydrological modeling (Rousseau, et al., 1999). This modeling estimated the net infiltration at the two geomorphic locations and the illustrated the differences in subsurface thermohydrologic conditions caused by presence or lack of alluvial cover and the differences in net infiltration.

Large-scale monitoring of infiltration and percolation such as the Alcove 1 and Pagany Wash tests could support assumptions, parameter estimates, and model results for net infiltration. Alcove 1 and Pagany Wash were the only tests conducted near Yucca Mountain at a scale similar to that used in the net infiltration model. Few details of these tests have been documented, thus limiting their utility to support model results.

1.3.2.1 DOE Documentation of Alcove 1 and Pagany Wash Tests

Analyses of bulk bedrock permeability for the Tiva Canyon fractured tuff above the Alcove 1 test, alluvium permeability derived from Pagany Wash monitoring, and bedrock permeability ranges for Yucca Mountain in general were presented in the DOE report. Net infiltration estimates are highly sensitive to bulk bedrock permeability where the soils are thin (approximately <50 cm thick), as is the case for much of the repository footprint. Furthermore, the value for bulk bedrock permeability is considered known in the calibration process for the net infiltration model (CRWMS, 2000b).

Influx rates at Alcove 1 represent a bulk bedrock permeability constraint. Influx rates higher than those used would lead to runoff, a condition that was avoided by design. Assuming dominantly one-dimensional flow and steady state, the influx rates would be a lower bound for the bulk bedrock permeability. The influx rates for the Alcove 1 test are 16 to 22 times larger than values used for the net infiltration model. The multiplier for bulk bedrock permeability in Table 4-1 of CRWMS (2000c) ranges from 0.05 to 20 for future climates, and 0.01 to 100 for modern climates. In the DOE report, it was noted that the maximum multiplier leads to bulk bedrock permeability values in the range of the influx rates used at Alcove 1.

Additionally, it is noted that air permeability measurements in the bedrock surrounding Alcove 1 are four orders of magnitude larger than the values of bulk bedrock permeability used in the net infiltration model. Arguments in the DOE report suggest that the caliche-filled fractures near the ground surface would be expected to lead to smaller values of bulk bedrock permeability as compared to the open fractures (not filled) further below the ground surface. Excerpts from a scientific notebook contained in the appendix of the DOE report note that bare bedrock was intentionally avoided in designing the drip application area at the ground surface. This implies that no ground preparation work, such as scraping off the surficial layers, was done on the drip application area (a search through the appropriate scientific notebooks would be needed to bear out this implication). Because fractures at the ground surface and at the soil/bedrock interface are typically filled with caliche or unconsolidated sediment (mostly eolian-derived fine sandy loams), the bedrock permeabilities derived from air-injection tests in boreholes would not be applicable to near-surface bulk bedrock permeability.

For the Pagany Wash monitoring, a recent published document (LeCain, et al., 2002) is cited as a source for an estimate of alluvial sediment permeability at UZ#5. This estimate is smaller than that used in the net infiltration model for colluvial/alluvial sediments, although it is within the range used for uncertainty analysis sampling (Table 4-1 of CRWMS, 2000c).

1.3.2.2 Staff Review of Data Presented from Alcove 1 and Pagany Wash Tests

Documentation of two tests relevant to near-surface, large-scale flow processes was requested as part of key technical issue Agreement USFIC.3.02. Documentation of the first test, the Alcove 1 artificial precipitation test, is limited to: (i) scientific notebook sketch maps of the infiltration site above Alcove 1; (ii) the data tracking numbers for the technical database management system for influx rates used in the tests; and (iii) an analysis of influx rate as compared to the bulk bedrock permeability values used in the net infiltration model. Information and data on other aspects of this large-scale infiltration, percolation, and seepage test are needed. The Alcove 1 test also included monitoring of hydrological conditions in the fractured tuff, monitoring of environmental conditions in the alcove, and collecting of water and tracers from the ceiling of Alcove 1. DOE has provided insufficient documentation and analyses of these aspects of the test. The Alcove 1 test results presented show the importance of understanding the spatial heterogeneity of fracture in-fill material. Alcove 1 documentation should include a discussion on infiltration control by spatial distribution of surface caliche and other material filled fractures in comparison with different climate stages.

Documentation of the Pagany Wash test was cited in the DOE report. The recently completed report by LeCain et al. (2002) on the Pagany Wash test was also considered for this review. LeCain et al. (2002): (i) describes the type of data collected and the locations, (ii) graphically presents important portions of the data, (iii) presents an analysis of the data including simulation of the wetting front using a numerical code. LeCain et al. (2002) appears to be an adequate description of the Pagany Wash test.

1.3.3 Sensitivity Analyses for Risk Importance

In addition to providing supporting bases for Table 4-1 of CRWMS (2000c) and information on Alcove 1 and Pagany Wash tests, the DOE report provided results from a dose-based, risk sensitivity study. The DOE report concludes that “uncertainties in the particular representation of the unsaturated zone flow system play little role in determining whether the repository system would meet the individual protection requirement of 15 mrem/yr" [0.15 mSv/yr]. Furthermore, it concludes that, "in the presence of waste packages and other engineered barriers, uncertainties in bedrock permeabilities used in the infiltration model are not important to a risk-informed performance assessment."

Net infiltration affects could affect dose in two primary ways, seepage into drifts and transport of radionuclides into and through the natural environment. The DOE report notes that the seepage rate into the drifts could affect the amount of water contacting the waste package, and in principle, could affect the degradation rate of the waste package. However, the DOE reports states that "detailed analyses based on experimental measurements indicate that degradation of the corrosion-resistant waste package material shows little sensitivity to amount of water contacting the waste package."

1.3.3.1 Total System Performance Assessment (TSPA) Sensitivity Study

The effect of net infiltration on transport of radionuclides was assessed using total system performance assessment sensitivity results. The DOE sensitivity studies compare mean annual dose estimates for a base case to an extreme infiltration case. The base case scenario uses the abstraction of infiltration from the supplemental site suitability analysis (Bechtel SAIC Company, 2002, 2001), with a net infiltration flux over the repository that averages about 12 mm/yr [0.47 in./yr] for the next 10,000 years. The extreme infiltration scenario considers an infiltration flux that averages 150 mm/yr [5.9 in./yr], more than an order of magnitude greater than the base case infiltration. The assigned net infiltration value (150 mm/yr [5.9 in./yr]) is only approximately a factor of 2 below the maximum estimated precipitation for the next 10,000 years. Mean annual dose estimates for the 100,000-year simulation period represent the average results of 300 stochastic realizations for each of the two cases. Comparisons between the base and extreme infiltration cases are provided for two scenarios, a "nominal scenario" and an "igneous activity groundwater scenario."

For the nominal scenario, results indicate that dose estimates are marginally higher for the extreme 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. 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 infiltration and seepage. The exhaustion of the inventory of highly soluble radionuclides may explain the reduction in dose for the extreme infiltration case during the 10,000 to 50,000 yr (approximate) period. However, 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 DOE report. Transparency and completeness in the description of the implementation of the extreme 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 extreme 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 extreme 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 DOE sensitivity studies indicate that using the extreme infiltration rate increases the estimated mean annual dose by less than 0.0001 mrem/yr [10^{-6} mSv/yr] for the nominal case and less than 0.01 mrem/yr [0.0001 mSv/yr] for the igneous activity case. DOE proposes that these increases in dose estimates are insignificant compared to the individual and groundwater protection standards specified in 10 CFR Part 63. Therefore, DOE concludes that net infiltration does not play a significant role in the postclosure performance and that details of the model for net infiltration are not important to the assessment of the ability of the repository system to meet the individual and groundwater protection performance objectives.

1.3.3.2 Staff Comments on the DOE Sensitivity Analyses

The sensitivity analyses provide valuable risk-insight into the importance of net infiltration in a total system performance assessment context and, combined with existing site data, may ultimately provide a sufficient basis for resolution of the shallow infiltration subissue of the Unsaturated and Saturated Flow Under Isothermal Conditions key technical Issue. However, the risk sensitivity study provided is not sufficiently documented to support the completion of Agreement USFIC.3.02 on the basis of low risk significance. In a recent letter,[6] NRC staff provided general comments to DOE regarding three types of additional information that would be necessary for a sufficiently developed risk argument to support closure of key technical issue agreements. These same information needs apply to the DOE sensitivity analyses provided in the response to Agreement USFIC.3.02. Specifically, DOE should address the following three comments:

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

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[6]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.

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 cases with extreme net infiltration rates. For example, while it is clear that the increased infiltration rates were applied to the unsaturated zone transport model, it is not clear how inputs to the seepage abstraction dynamic linked library were modified for the sensitivity analyses.

DOE has reasonably addressed some elements of item 2 (above) in the current or other recent agreement submittals. Figure 1 on page 19 of the DOE report on 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 introduced for the extreme infiltration analysis is quite pessimistic compared to the data provided in Figure 1. In a recent letter report, DOE provided a reasonable description of additional potential effects of increased water flow that may not be explicitly represented in the model.[7] The explanation of the model output provided on page 20 is reasonable (e.g., the radionuclides that dominate the mean annual dose for the next 10,000 years are dominated by highly-soluble and mobile species, Tc-99 and C-14, whose release is not significantly affected by the amount of water present). In addition, the analysis for extreme infiltration tests the sensitivity of very high infiltration rates only. An "increase in magnitude of the expected annual dose" would occur (at low dose levels) if very low infiltration rates were analyzed. The explanation of the model results could be improved with simple physical arguments (e.g., describing the rate of water entering a package to mobilize the Tc-99 released from the wasteforms each year) or through the presentation of intermediate outputs.

An adequate description of what changes were made to the model for the analysis is needed. The text for the USFIC.3.02 letter report identifies that the infiltration rate was modified, but it is unclear what other parameters or models were modified. Since infiltration rates and most seepage abstraction model inputs are not explicit input parameters in the TSPA model, it is the NRC's understanding that these parameters would need to have been modified manually by the analyst (i.e. the TSPA model would not perform an automatic update of infiltration rate inputs to the seepage dynamic linked library (DLL)). While it is clear that the increased infiltration rates were applied to the unsaturated zone transport model, it is not clear how inputs to the seepage abstraction DLL were modified for the sensitivity analyses. It is the NRC's understanding that the record package developed for the analysis contains an adequate description of the changes to the base case TSPA model.

[7]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.

3. To convey uncertainty in the analyses, DOE should provide information on the variability of simulation results for the extreme infiltration 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.

1.4 Additional Information Needs

The DOE report provided both the information to address the topic of the USFIC.3.02 agreement and results of total system performance assessment simulations that illustrated the lack of sensitivity of dose to very high net infiltration rates. Agreement USFIC.3.02 can be satisfactorily resolved using either approach.

If information is supplied on the topic of USFIC.3.02:

- Additional support of values in the parameter distribution table for glacial transitional climates (Table 4-1 of CRWMS, 2000c) is needed. This information would include the technical bases for reducing the parameter ranges and changing the mean values from those used for the modern climate. Model self-consistency was also inferred as a justification for changing parameter distributions for the glacial transition climate. Transparency or clarification of the model self-consistency argument and basis are needed.

- Alcove 1 test documentation needs to be complete.

Alternatively, if the risk-informed approach is chosen:

- 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. It is expected that the following information would be presented: (i) combined effect of uncertainty associated with agreements addressed with risk information; (ii) transparency of changes made to implement the sensitivity analyses and explanation of the results; and (iii) details on the distribution of simulation results.

In addition, detailed analyses were used to conclude that the quantity of water contacting the waste package was not important. Therefore, changes to DOE total system performance assessment and to detailed process models that may have relegated the issues of the USFIC.3.02 agreement as unimportant to dose, will lead to a reassessment of USFIC.3.02. Specifically, significant changes to the understanding and implementation of corrosion models or engineered barrier subsystems (e.g., drip shield and the alloy 22 of the waste package) could cause the quantity of water contacting the waste to become risk-significant.

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.

1.5 Status of Agreement

The key technical issue Agreement USFIC.3.02 has the status “additional information needs”, pending receipt of additional information listed in Section 1.4 of this review.

2 Agreement TSPAI.3.22

2.1 Wording of the Agreement

TSPAI.3.22 states: "Provide an assessment or discussion of the uncertainty involved with using a hydrologic property set obtained by calibrating a model on current climate conditions and using that model to forecast flow for future climate conditions (UZ2.3.1). DOE will provide an assessment or discussion of the uncertainty involved with using a hydrologic property set obtained by calibrating a model on current climate conditions and using that model to forecast flow for future climate conditions. This assessment will be documented in the UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006) expected to be available to NRC in FY 2003."

2.2 Background

The unsaturated zone flow model is calibrated to present-day climate and extrapolated to future climate states with limited technical basis for this extrapolation. The amount of flux and the transport of radionuclides in the unsaturated zone under various climatic conditions are obtained from flow fields generated with the unsaturated zone flow model. Net infiltration rates control the development of the flow fields over time. Uncertainties in the assessment of repository performance may be impacted due to the uncertainties of the net infiltration rate affecting the representation of the unsaturated zone flow fields. Unsaturated zone flow could affect dose in two primary ways, seepage into drifts and transport of radionuclides into and through the natural environment.

2.3 NRC Review of Sensitivity Analyses for Risk Importance

2.3.1 TSPA Sensitivity Study

The effect of net infiltration on transport of radionuclides was assessed using total system performance assessment sensitivity results. The DOE sensitivity studies compare mean annual dose estimates for a base case to an extreme infiltration case. The base case scenario uses the abstraction of infiltration from the supplemental site suitability analysis (Bechtel SAIC Company, 2002, 2001), with a net infiltration flux over the repository that averages about 12 mm/yr [0.47 in./yr] for the next 10,000 years. The extreme infiltration scenario considers an infiltration flux that averages 150 mm/yr [5.9 in./yr], more than an order of magnitude greater than the base case infiltration. The assigned net infiltration value (150 mm/yr [5.9 in./yr]) is only approximately a factor of 2 below the maximum estimated precipitation for the next 10,000 yrs. Mean annual dose estimates for the 100,000-year simulation period represent the average results of 300 stochastic realizations for each of the two cases. Comparisons between the base and extreme infiltration cases are provided for two scenarios, a "nominal scenario" and an "igneous activity groundwater scenario."

The DOE sensitivity studies indicate that using the extreme infiltration rate increases the estimated mean annual dose by less than 0.0001 mrem/yr [10^{-6} mSv/yr] for the nominal case and less than 0.01 mrem/yr [0.0001 mSv/yr] for the igneous activity case. DOE proposes that these increases in dose estimates are insignificant compared to the individual and groundwater protection standards specified in 10 CFR Part 63. Therefore, DOE concludes that net infiltration does not play a significant role in the postclosure performance and that details of the model for net infiltration are not important to the assessment of the ability of the repository system to meet the individual and groundwater protection performance objectives.

A second sensitivity study examines the sensitivity of mean annual dose to full neutralization of the unsaturated zone and saturated zone radionuclide transport barriers and to neutralization of only the transport processes. Comparisons between the base and extreme infiltration cases, and between the base and neutralization cases, are provided for two scenarios, a "nominal scenario" and an "igneous activity groundwater release scenario." Neutralizing all natural barrier parameters effectively discharges the radionuclides released from the engineered barrier system directly to wells in Amargosa Valley, so that no assumptions about sorption, colloid filtration, matrix diffusion, or radionuclide transport in fractures or the matrix are included nor necessary. At 10,000 years in the nominal case, the mean annual dose for the neutralized case is more than two orders of magnitude higher than the base case, however well below 15 mrem. A further sensitivity study showed the results of neutralizing only transport parameters (flow parameter was not neutralized). The results from this sensitivity analysis showed that flow alone does not have a significant effect on the estimate of mean annual dose after 700 years.

2.3.2 Staff Comments on the DOE Sensitivity Analyses

The sensitivity analyses provide valuable risk-insight into the importance of net infiltration in a total system performance assessment context and, combined with existing site data, may ultimately provide a sufficient basis for resolution of the shallow infiltration subissue of the Unsaturated and Saturated Flow Under Isothermal Conditions key technical Issue. However, the risk sensitivity study provided is not sufficiently documented to support the completion of Agreement TSPAI.3.22 on the basis of low risk significance. In a recent letter,[8] NRC staff provided general comments to DOE regarding three types of additional information that would be necessary for a sufficiently developed risk argument to support closure of key technical issue agreements. These same information needs apply to the DOE sensitivity analyses provided in the response to Agreement TSPAI.3.22. Further, detailed comments provided in Section 1.3.3.2 of this review on aspects of DOE's resolution of Agreement USFIC.3.02 using sensitivity analyses also apply to Agreement TSPAI.3.22.

2.4 Additional Information Needs

Satisfactory information to address the technical topic of the agreement would be sufficient to complete Agreement TSPAI.3.22. DOE had proposed to compare modeling predictions with actual test results from field tests (such as Alcove 8 - Niche 3) conducted at higher flow rates

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[8]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.

that are expected to encompass flow behavior representative of future climates. Alternatively, sensitivity analyses which adequately address NRC's concerns with DOE's approach to resolving agreements via risk arguments would be sufficient to complete the agreement. 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.

It is expected that the following information would be presented: (i) combined effect of uncertainty associated with agreements addressed with risk information; (ii) transparency of changes made to implement the sensitivity analyses and explanation of the results; and (iii) details on the distribution of simulation results. Detailed comments provided in Section 1.3.3.2 of this review on aspects of DOE's resolution of Agreement USFIC.3.02 using sensitivity analyses also apply to Agreement TSPAI.3.22.

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.

2.5 Status of Agreement

The key technical issue Agreement TSPAI.3.22 has the status "additional information needs", pending receipt of additional information discussed in Section 2.4 of this review.

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