THE U.S. NUCLEAR REGULATORY COMMISSION OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY KEY TECHNICAL ISSUE AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA: UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS 3.01,3.02; AND TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION.3.18, 3.19, AND 3.21

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this interim prelicensing period is to assure the U.S. Department of Energy (DOE) has assembled enough information about a given issue for NRC to accept a license application for review. Resolution by the NRC staff during prelicensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. Also, and just as important, resolution of an issue by the NRC staff during prelicensing does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are resolved by the NRC staff during prelicensing when the staff has no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments about a previously resolved issue.

By a letter dated May 7, 2004, DOE submitted a report titled "Technical Basis Document No. 1 (TBD No. 1): Climate and Infiltration," (Bechtel SAIC Company, LLC, 2004) that contains responses to five Key Technical Issue (KTI) agreements in Appendixes A–E. This enclosure contains the results of the NRC staff review for those agreement responses.

2.0 BACKGROUND AND WORDING OF THE AGREEMENTS

The appendixes of Bechtel SAIC Company, LLC (2004) provide DOE's responses to Agreements Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC).3.01, 3.02 Total System Performance Assessment and Integration (TSPAI).3.18, 3.19 and 3.21. The wordings of these agreement items are as follows:

USFIC.3.01

"Provide the documentation sources and schedule for the Monte Carlo method for analyzing infiltration. DOE will provide the schedule and identify documents expected to contain the results of the Monte Carlo analysis in February 2002."

DOE initially responded to Agreement USFIC.3.01 in July 2002 (Ziegler, 2002a). After review of the initial DOE submittals, NRC requested additional information in the January 27, 2003, risk letter (Schlueter, 2003c) consisting of: (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.

USFIC.3.02

“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 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 analysis document. The information will be available in February 2002.”

DOE initially responded to Agreement USFIC.3.02 in November 2002 (Ziegler, 2002b). After review of the initial DOE submittals, NRC requested (Schlueter, 2003a) DOE to provide additional information as discussed in the January 27, 2003, risk letter (Schlueter, 2003c).

TSPAI.3.18

“Provide a technical basis that the water-balance plug-flow model adequately represents the non-linear flow processes represented by Richard’s equation, particularly over the repository where there is thin soil (UZ.1.2.1). The DOE will provide a technical basis that the water-balance plug-flow model adequately represents the non-linear flow processes represented by Richard’s equation, particularly over the repository where there is thin soil. The technical basis will be documented in an update to Simulation of Net Infiltration for Modern and Potential Future Climates AMR (AMR–NBS–HS–000032). The AMR is expected to be available to the NRC in FY 2003.”

DOE initially addressed Agreement TSPAI.3.18 in a letter report on January 21, 2003 (Ziegler, 2003). After review of the initial DOE submittal, NRC requested (Schlueter, 2003b) DOE to provide additional information as discussed in the January 27, 2003, risk letter (Schlueter, 2003c).

TSPAI.3.19

“DOE will provide justification for the use of its evapotranspiration model, and defend the use of the analog site temperature data (UZ.1.3.1). DOE will provide justification for the use of the evapotranspiration model, and justify the use of the analog site temperature data. The justification will be documented in an update to the Simulation of Net Infiltration for Modern and Potential Future Climates AMR (ANL–NBS–HS–000032) and the Future Climate Analysis AMR (ANL–NBS–GS–000008). The AMRs are expected to be available to NRC in FY 2003.”

DOE initially addressed Agreement TSPAI.3.19 in a letter report on July 11, 2002 (Ziegler, 2002a). After review of the initial DOE submittal, NRC requested additional information (Schlueter, 2003c) consisting of: (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.

TSPAI.3.21

“Demonstrate that effects of near surface lateral flow on the spatial variability of net infiltration are appropriately considered (UZ.1.5.1). DOE will demonstrate that effects of near surface lateral flow on the spatial variability of net infiltration are appropriately considered in an update to the Simulation of Net Infiltration for Modern and Potential Future Climates AMR (ANL–NBS–HS–00032) and UZ Flow Models and Submodels AMR (MDL–NBS–HS–000006). These AMRs are expected to be available to NRC in FY 2003."

DOE initially addressed Agreement TSPAI.3.21 in a letter report on January 21, 2003 (Ziegler, 2003). After review of the initial DOE submittal, NRC requested (Schlueter, 2003d) DOE to provide additional information as discussed in the January 27, 2003, risk letter (Schlueter, 2003c).

3.0 RELEVANCE TO REPOSITORY PERFORMANCE

These agreements all relate to the reliability of the numerical modeling used by DOE to estimate net infiltration at Yucca Mountain under present-day and future climate conditions. Climate and infiltration ultimately control the volume of water that is available to reach the repository horizon. Some precipitation that falls on Yucca Mountain is expected to move into the bedrock as net infiltration. Estimates of present-day net infiltration rates are used to represent the deep percolation rate at the repository horizon. Some fraction of this deep percolation is expected to seep into the repository drifts and contact the engineered barrier system. In the event of a failure in the drip shield, water coming into contact with waste packages could affect waste package corrosion rates. The release of radionuclides from failed waste packages would be increased by water contacting the waste form. The net infiltration rate and, thus, deep percolation rate also directly affect the transport of radionuclides from the repository horizon to the saturated zone.

The mathematical model developed to simulate infiltration at Yucca Mountain (U.S. Geological Survey, 2001) serves four purposes in the analysis of repository performance. First, it is used to estimate average net infiltration over the repository footprint under present-day climate conditions. It complements estimates of net infiltration made from analysis of various types of empirical data. The importance of estimates of present-day net infiltration based on the infiltration model depends on the reliability of analyses of empirical data on infiltration used to support those estimates. Second, the infiltration model is used to simulate the areal distribution of infiltration over the footprint of the repository. In this mode, the importance of the infiltration estimates from the model increases because the model provides estimates in areas that do not have any type of supporting infiltration estimate. Third, the infiltration model provides the primary basis for estimating average net infiltration and the spatial distribution of infiltration for the future climate states. The results of the model are supported, to some extent, by estimates of net infiltration believed to represent water that infiltrated during past glacial or glacial transition climate conditions. Fourth, the model is the basis for analyzing the uncertainty in infiltration estimates under present and future climatic conditions, and for developing net infiltration probability distributions that are used to select net infiltration maps used in the performance assessment simulations.

The estimates of infiltration and deep percolation for modern and future climate conditions are affected by uncertainties in:

- Data used to describe the characteristics of future climate states;
- Data used to describe the timing of the sequence of climate states;
- Data used to describe hydraulic and other properties affecting net infiltration; and

- Uncertainties in the conceptual and mathematical models used to estimate infiltration.

Based on these considerations, uncertainties in net infiltration for both the present-day and future climates must be adequately propagated in the abstractions for total system performance assessment. The agreements addressed here requested information needed for staff to understand and evaluate DOE's approaches for developing ranges of net infiltration to be used for total system performance assessment.

4.0 NRC EVALUATION AND COMMENT

USFIC.3.01

DOE's response to USFIC.3.01 presented in Appendix D of Bechtel SAIC Company, LLC (2004) provides the mean, range, and probability distribution assigned to 12 parameters considered in "Analysis of Infiltration Uncertainty" (Bechtel SAIC Company, LLC, 2003). Justification for the selection of these parameter values and ranges is given in the response to USFIC.3.02. Appendix D includes two figures (D–2 and D–3) showing histograms of the frequency of average annual net infiltration for the glacial-transition climate with and without the repository footprint contingency area. Weighting factors for selecting between lower bound, mean, and upper bound net infiltration maps for use in the total system performance assessment model are based on these histograms. The text lists the weighting factors determined for each case and states that the weighting factors were determined from the infiltration frequency distribution. How the weighting factors were determined is not documented in TBD No. 1 (Bechtel SAIC Company, LLC, 2004), but is described in (Bechtel SAIC Company, LLC, 2003). The weighting factors derived from the glacial-transition climate uncertainty analyses were also used for the present climate and monsoon climate analyses.

DOE describes the methodology for determining weighting factors for selecting the net infiltration maps used in total system performance assessment based on the frequency distribution of outcomes from the Monte Carlo simulations of net infiltration uncertainty as a "simple graphical procedure" (Bechtel SAIC Company, LLC, 2003). The histograms describing the frequency distributions of the outcomes from the Monte Carlo analysis based on the Tule Lake analog climate data were divided into three parts. The central portion was determined by first taking the average of the net infiltration rates determined from simulating the lower and upper bound climate analog site data using the calibrated infiltration model parameters (with the exception of parameters such as root depth and vegetation cover that were adjusted for the glacial transition climate simulations). The simulated lower and upper bound infiltration rates for the repository area (including the repository contingency area) were 2 mm/yr [0.08 in/yr] and 33 mm/yr [1.3 in/yr], respectively. Their average {17.5 mm/yr [0.7 in/yr]} was rounded to 17 mm/yr [0.7 in/yr]. Second, the lower boundary of the central part was determined from the average of the lower bound infiltration rate {2 mm/yr [0.08 in/yr]} and the average of the lower and upper bound infiltration rates {17 mm/yr [0.7 in/yr]}, yielding 9.5 mm/yr [0.37 in/yr]. The upper boundary of the central part was defined as the average between the average {17 mm/yr [0.7 in/yr]} and the upper bound infiltration rate {33 mm/yr [1.3 in/yr]} yielding 25 mm/yr [1 in/yr]. The boundaries of the lower part of the frequency distribution were 0 mm/yr and 9.5 mm/yr [0.37 in/yr] (the lower bound of the central part). All outcomes exceeding the upper boundary of the central part were assigned to the upper part. The weighting factor (40 percent) assigned to the average net infiltration rate was then based on the percentage of outcomes falling within the central part of the frequency distribution, as described above. Similarly, the weighting factor (22 percent) assigned to the lower bound infiltration rate {2 mm/yr [0.08 in/yr]} was the percentage of infiltration outcomes falling in the lower part of the frequency distribution. Finally, the weighting factor (38 percent) for the upper bound infiltration rate {33 mm/yr [1.3 in/yr]} was based on the percentage of outcomes in the upper part of the frequency distribution. The weighting factors determined in this way for the glacial-transition climate were also used to select the infiltration scenarios for the present and monsoon climate states.

Staff is concerned that the methodology used by DOE to select the infiltration maps and weighting factors for the glacial transition climate does not adequately reflect the uncertainty in the infiltration estimates. For example, approximately 27 percent of the net infiltration outcomes from the Monte Carlo analysis of infiltration uncertainty shown in Figure D–2 of Appendix D exceed the upper bound infiltration rate of 33 mm/yr [1.3 in/yr] that is assigned a weighting factor of 38 percent. Additionally, a weighting factor of 22 percent was assigned to the lower bound infiltration rate of 2 mm/yr [0.08 in/yr] and this rate is exceeded by more than 95 percent of the uncertainty analysis outcomes. Thus, DOE's methodology for selecting infiltration maps for total system performance assessment will over represent the lower bound infiltration estimate and fail to include a substantial portion of the higher infiltration estimates.

DOE's approach assumes a special status for the net infiltration analog values computed from the lower and upper bound analog site climate records using the calibrated infiltration model parameters (U.S. Geological Survey, 2001). Because uncertainty exists in the applicability of the analog site data to Yucca Mountain and the calibrated infiltration model parameters, the particular results of the analog site data could be viewed as simply two potential outcomes that could have resulted from the Monte Carlo analysis. One possible reasonable approach would be to use the uncertainty analysis results to select the infiltration rate maps and weighting factors to be used in the total system performance assessment (TSPA) by dividing the Monte Carlo frequency distribution into three equal parts with a third of the outcomes in each part.

Staff finds the technical basis for the methodology used to select the infiltration maps and weighting factors for TSPA lacks justification (e.g., rationale for following an ad hoc procedure to calculate the net infiltration weighting factors using analog values from Attachment IV (Bechtel SAIC Company, LLC, 2004). Therefore, the NRC staff finds the information provided is not sufficient to satisfactorily address this issue.

<u>USFIC.3.02</u>

Agreement USFIC.3.02 is closely related to USFIC.3.01 and is addressed by DOE in Appendix E of Bechtel SAIC Company, LLC (2004) by providing the justification for the mean, ranges, and probability distribution assigned to twelve parameters considered in Bechtel SAIC Company, LLC (2003). NRC review (Schlueter, 2003b) of DOE's initial response to USFIC.3.02 (Ziegler, 2002b) raised questions regarding changes made to certain infiltration model parameters between the uncertainty analyses for the present-day climate and the glacial transition climate. The parameters addressed were:

- Bedrock permeability (BRPERM);
- Soil permeability (SOILPERM);
- Bedrock root zone depth (BRZDEPTH);

- Soil depths (SOILDEPM);
- Precipitation multiplier (PRECIPM); and
- Surface runoff factor (FLAREM).

The questions raised were based on CRWMS M&O (2000). This document was significantly revised by DOE as Bechtel SAIC Company, LLC (2003). The values of BRPERM, SOILPERM, SOILDEPM, and PRECIPM in the revised document were the same for both the present-day and glacial transition climate analyses, thus rendering some of the issues raised in the 2003 staff comments no longer relevant. With respect to the parameters that still differed between the two climate states (BRZDEPTH and FLAREM), DOE explained its selection of parameter values, ranges, and distributions in Appendix E of TBD No. 1 (Bechtel SAIC Company, LLC, 2004).

The 2003 NRC review also identified DOE's choice of the parameter range for the precipitation multiplier for the present-day climate as lacking transparency. DOE provided additional explanation based on historical climate records for the choice of this parameter range in Appendix E of TBD No.1 (Bechtel SAIC Company, LLC, 2004).

In addition, Agreement USFIC.3.02 requested documentation for the Alcove 1 and Pagany Wash infiltration and seepage tests. Appendix E provides information on and references to the Alcove 1 test, while the information on the Pagany Wash testing has been published by the U.S. Geological Survey in LeCain and Kurzmack (2001) and LeCain, et al. (2002). Based on the information provided in Appendix E and the publically available data on the Pagany Wash tests, staff conclude that sufficient information has been provided on the these tests.

On the basis of this review, and notwithstanding new information that could raise new questions or comments concerning the preceding agreements, staff find that DOE's response to Agreement USFIC.3.02 provides information to conclude that adequate information on the specification of parameter values and ranges for the analysis of infiltration uncertainty will be available to review a potential license application.

<u>TSPAI.3.18</u>

The net infiltration estimates developed from the infiltration model depend on the interaction of multiple hydrologic processes that are also subject to uncertain model inputs and approximation in their mathematic representation, such as are addressed in Agreements TSPAI.3.18, 3.19 and 3.21. Agreement TSPAI.3.18 addresses whether or not the water-balance, plug-flow model used to simulate the vertical movement of water in the soil and shallow bedrock adequately represents the nonlinear flow processes, as described by the Richards equation, as they relate to the simulation of net infiltration at Yucca Mountain. DOE's response to this agreement in Appendix A (Bechtel SAIC Company, LLC, 2004) is based on comparing the net infiltration estimates generated by the infiltration model with estimates based on interpretations of various types of empirical data. In addition, the estimates from the infiltration model were compared to estimates reported to have been developed by calibrating the unsaturated zone flow and transport model to match the chloride distribution measured in pore waters at Yucca Mountain. Because the estimates derived from the net infiltration model fall within the range of estimates developed from these other approaches, DOE concludes that the net infiltration model and, by implication, the plug-flow model have been validated. Flint, et al. (2002) reviewed many of these independent approaches for estimating infiltration at Yucca Mountain and considered their strengths and weaknesses. A weakness common to all of the approaches is that the data are heavily influenced by the water content and water chemistry of the tuff matrix, and they are less sensitive to water movement in the fractures. In addition, some of the infiltration estimates are not truly independent of the infiltration model because the data were used in calibration of certain aspects of the infiltration model (e.g., borehole neutron moisture profiles). It also is uncertain whether some of the geochemical data from which net infiltration has been estimated represent the present-day climate or paleoclimate conditions with greater precipitation. Zhu, et al. (2003) developed net infiltration estimates for the saturated zone and perched water at Yucca Mountain based on the chloride mass balance approach and Cl-36 analyses that range from 5 to 15 mm/yr [0.20 to 0.50 in/yr]. The lower values were interpreted as representing Holocene (roughly modern) net infiltration and the higher values late Pleistocene (transitional between glacial and interglacial climates). These recharge estimates are consistent with the net infiltration estimates derived from DOE's infiltration model.

The water-balance, plug-flow approach used by DOE is similar to that used in other models for estimating net infiltration, such as Hydrologic Evaluation of Landfill Performance (HELP) (Schroeder, et al., 1994). An independent study by Khire, et al. (1997) compared the net infiltration (percolation) computed by HELP and an infiltration model, UNSAT-H, based on the Richards equation (Fayer and Jones, 1990), with measured net infiltration through landfill covers at a humid climate site in Georgia and a semi-arid landfill site in Washington state. Their analysis indicated that HELP overpredicted net infiltration at the humid site and both models underpredicted infiltration at the semi-arid site. The overprediction of net infiltration by HELP at the humid site was attributed to the water-balance, plug-flow representation of soil water movement in HELP. They explained the failure of both HELP and UNSAT-H to correctly predict net infiltration at the semi-arid site as being due to focused infiltration through cracks and animal burrows in the soil. Chammas, et al. (1999) compared the results of infiltration estimates using HELP with estimates using a model, SoilCover, based on the Richards equation (Geo-Analysis 2000 Ltd., 1997) at a semi-arid mill tailings site. Although they had no empirical data with which to compare the model results, they found that HELP produced much higher predictions of net infiltration than SoilCover. Based on the studies by Khire, et al. (1997) and Chammas, et al. (1999), the water-balance, plug-flow approach in DOE's infiltration model has the potential to overestimate net infiltration relative to an approach based on the Richards equation.

Based on the independent studies cited above, uncertainties in the estimation of net infiltration transcend the issue of the use of the water-balance, plug-flow concept versus the Richards equation. Recognizing that uncertainties exist in the representation of unsaturated flow processes in DOE's infiltration model, the infiltration estimates generated using DOE's model fall into the broad range of estimates derived from empirical studies and supporting lines of evidence (Bechtel SAIC Company, LLC, 2004; Flint et al., 2002). Thus, on the basis of this review, and notwithstanding new information that could raise new questions or comments concerning the preceding agreements, DOE has provided sufficient information on vertical movement of water in soil and shallow bedrock to satisfactorily address Agreement TSPAI.3.18. Staff notes, this technical issue is closely tied to successfully propagating sufficient net infiltration uncertainty in the infiltration model abstraction, as discussed in the preceding review of Agreement USFIC.3.01. DOE should consider activities, including water balance studies on small watersheds at Yucca Mountain, that will provide data for further testing the infiltration modeling approaches used by DOE.

TSPAI.3.19

Agreement TSPAI.3.19 requested additional justification for the use of the modified Priestley-Taylor evapotranspiration model in the simulation of net infiltration. It also requested justification for the analog site temperature data used to represent future climates in modeling net infiltration. Based on the water balance tables derived from the net infiltration simulations presented in U.S. Geological Survey (2001), evapotranspiration losses ranged from 92 percent of annual average precipitation for the upper bound glacial transition climate to 99.5 percent of precipitation for the lower bound present-day climate. Runoff from the infiltration model area was less than 1 percent of precipitation for all of the climate states simulated. Thus, the amount of water potentially available to become net infiltration is primarily controlled by the evapotranspiration calculations in the model. Consequently, small errors in the calculated evapotranspiration losses could result in large relative errors in the computed net infiltration. For this reason, staff intent in developing TSPAI.3.19 was to assure a detailed understanding of DOE’s approach to computing evapotranspiration losses given their importance to estimation of net infiltration.

In addition to describing the evapotranspiration model, DOE’s response in Appendix B (Bechtel SAIC Company, LLC, 2004) references two studies used to support selection of the modified Priestley-Taylor evapotranspiration model: Flint and Childs (1991) and Levitt, et al. (1996). Levitt, et al. (1996) describes a study at the Area 5 Radioactive Waste Management Site at the Nevada Test Site that concluded the parameters in the Priestley-Taylor evapotranspiration model could be adjusted to match empirical measurements and estimates of evapotranspiration. However, the evapotranspiration parameters used in the net infiltration modeling of Yucca Mountain (U.S. Geological Survey, 2001) were calibrated using the model to match soil moisture profiles estimated from neutron moisture logging of boreholes at selected locations at Yucca Mountain rather than directly using measurements or estimates of evapotranspiration. Thus, although the parameters in the Priestley-Taylor model can be calibrated to relatively accurately represent evapotranspiration for particular soil and vegetation conditions given direct measurements or reliable estimates of evapotranspiration, applying these same parameters to locations with different soils and vegetation for which evapotranspiration has not been measured introduces uncertainty in the model results. In this case, the Yucca Mountain infiltration model, includes various soil types, thicknesses, and vegetation densities, all of which can affect the values of the parameters used in the evapotranspiration model. For these reasons, the estimates of evapotranspiration in the net infiltration modeling are subject to uncertainty.

The rationale used to select analog sites describing future climates is presented in Section B.4.6 of Appendix B of Bechtel SAIC Company, LLC (2004). Staff interest in the use of the analog site temperature data to describe future climates at Yucca Mountain related to the influence of temperature on evapotranspiration. Specifically, staff questioned if the temperature histories at the analog sites were transferable to Yucca Mountain and how uncertainties in the future climate temperatures would affect the estimation of net infiltration. DOE’s response consists of a discussion of the rationale for selecting the analog sites and an analysis of the sensitivity of the potential evapotranspiration to temperature.

Staff find the information provided to be adequate to evaluate the influence of the evapotranspiration model and analog site temperature data on DOE’s net infiltration estimates. Recognizing that uncertainties exist in the representation of unsaturated flow processes in DOE’s infiltration model, the infiltration estimates generated using DOE’s model fall into the broad range of estimates derived from empirical studies and supporting lines of evidence. Thus, on the basis of this review, and notwithstanding new information that could raise new questions or comments concerning the preceding agreements, DOE has provided sufficient information on the influence of the evapotranspiration model and analog site temperature data on DOE's net infiltration estimates to satisfactorily address Agreement TSPAI.3.19. Staff notes, this technical issue is closely tied to successfully propagating sufficient net infiltration uncertainty in the infiltration model abstraction, as discussed in the preceding review of Agreement USFIC.3.01. DOE should consider activities, including water balance studies on small watersheds at Yucca Mountain, that will provide data for further testing the infiltration modeling approaches used by DOE.

TSPAI.3.21

TSPAI.3.21 requests a demonstration that the effects of lateral flow of water in the near surface on the spatial distribution of net infiltration have been appropriately considered in DOE's net infiltration model. In Appendix C (Bechtel SAIC Company, LLC, 2004), DOE addresses this agreement using five basic arguments.

- Lateral subsurface flow may influence the redistribution of moisture and, therefore, infiltration; however, this process most likely occurs within the 30 × 30-m [98 × 98-ft] gridblocks of the infiltration model.

- Lateral surface flow redistribution of water is accounted for indirectly in the water-balance model as mass is conserved at the spatial and temporal scales in the model.

- The potential influence of lateral flow would be expected to be a small percentage change in net infiltration, which is a small total volume of water relative to precipitation.

- Any influence of lateral redistribution on net infiltration would be expected to be secondary to the dominant factors of precipitation, soil moisture storage, evapotranspiration, and gravity drainage in preferential flow pathways.

- Infiltrating water diverted laterally (as subsurface flow) within the soil will experience greater time for evapotranspiration (particularly in depositional valley regions) as the dominant flow vector is upward for a majority of the year. This would suggest that net infiltration estimates that do not account for lateral flow should overestimate water volumes and could, therefore, be a conservative assumption.

The responses in Appendix C alone do not adequately address Agreement TSPAI.3.21. With regard to the effect of runoff between cells in the model domain on the net infiltration estimates, DOE's response is that: (i) the INFIL model conserves water volume; and (ii) redistribution of water from ridge tops and hillsides to the valleys due to lateral flow would tend to reduce net infiltration because of greater evapotranspiration losses in the relatively thick soil and alluvium in the valleys. The second component of DOE's response, although possibly valid, is difficult to confirm without simulating the actual response of a watershed to increased lateral flow. Inspection of the water balance tables (such as Table 6-7) derived from the net infiltration simulations in U.S. Geological Survey (2001) indicates that mean shallow infiltration due to redistribution of surface water represents less than 10 percent of precipitation within the model domain. This result implies that most of the precipitation that becomes net infiltration enters the subsurface in the same model cell in which it falls. Thus, the net infiltration model predicts relatively little redistribution of precipitation due to surface runoff processes. The conclusion that increased lateral surface flow would result in less net infiltration cannot be confirmed based on the simulations that have been reported. Additional analysis of the sensitivity of the simulated net infiltration to parameters such as soil permeability and the size of the time step would be required to determine how increased lateral flow would affect net infiltration and its lateral distribution. The importance of the lateral distribution of net infiltration to repository safety also depends on the extent to which variations in shallow infiltration are smoothed as the water percolates through deeper geological units above the repository horizon.

With respect to subsurface lateral flow processes, staff reviewed independent investigations of lateral subsurface flow processes reported in Wilcox, et al. (1997) for a watershed underlain by tuff at Los Alamos National Laboratory. Based on comparison of soil and bedrock conditions at Yucca Mountain, staff conclude that the uncertainty in the effect of lateral subsurface flow at Yucca Mountain on net infiltration and the spatial distribution of net infiltration is less than the uncertainty in other factors affecting these processes. For example, Wilcox, et al. (1997) found that lateral subsurface flow accounted for less than 2 percent of the annual water balance. In general, the climatic, soil and bedrock conditions at the site studied by Wilcox, et al. (1997) were more favorable for the development of lateral subsurface flow than those at Yucca Mountain due to higher annual precipitation, greater snow accumulation, a forested watershed with thick soil, and relatively low permeability of weathered tuff and soil contact at the Los Alamos site. Although topographic slopes are steeper at Yucca Mountain, soils are generally thinner reducing the potential for development of thick saturated zones.

Infiltration uncertainties in the estimation of net infiltration as discussed in the section reviewing Agreement USFIC.3.01 surpass the issue of surface and subsurface lateral flow representation in significance. Recognizing that uncertainties exist in the representation of unsaturated flow processes in DOE’s infiltration model, the infiltration estimates generated using DOE model fall into the broad range of estimates derived from empirical studies and supporting lines of evidence (Bechtel SAIC Company, LLC, 2004; Flint et al., 2002). Thus, on the basis of this review, and notwithstanding new information that could raise new questions or comments concerning the preceding agreements, DOE has provided sufficient information on the justification for the representation of near-surface flow processes to satisfactorily address Agreement TSPAI.3.21. Staff notes, this technical issue is closely tied to successfully propagating sufficient net infiltration uncertainty in the infiltration model abstraction, as discussed in the preceding review of Agreement USFIC.3.01. DOE should consider activities, including water balance studies on small watersheds at Yucca Mountain, that will provide data for further testing the infiltration modeling approaches used by DOE.

5.0 SUMMARY OF THE AGREEMENTS

The NRC staff has reviewed DOE’s KTI agreement responses provided in Appendixes A–E of TBD No. 1: Climate and Infiltration (Bechtel SAIC Company, LLC, 2004) to determine if sufficient information on these technical agreement items will be available for review of a potential license application. The NRC staff reviewed DOE’s agreement response for Agreement USFIC.3.01 and found the methodology used by DOE to select infiltration maps and weighting factors does not adequately reflect the uncertainty in infiltration estimates. The NRC staff finds the information provided is not sufficient to satisfactorily address this issue. Staff will review a potential license application to determine whether sufficient information is provided to justify the methodology used or to determine the overall importance of infiltration uncertainty to waste isolation.

The NRC staff has also reviewed DOE's responses to Agreements USFIC.3.02, TSPAI.3.18, 3.19, and 3.21. Recognizing that uncertainties exist in the representation of unsaturated flow processes in DOE's infiltration model, the infiltration estimates generated using DOE's model fall into the broad range of estimates derived from empirical studies and supporting lines of evidence (Bechtel SAIC Company, LLC, 2004; Flint et al., 2002). Thus, on the basis of this review, and notwithstanding new information that could raise new questions or comments concerning the preceding agreements, DOE has provided sufficient information to satisfactorily address these agreements. The NRC staff will make its final determination on any issues relevant to licensing during review of any license application.

6.0 REFERENCES

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