December 3, 2003

Joseph D. Ziegler, Director
Office of License Application and Strategy
U.S. Department of Energy
Office of Repository Development
P.O. Box 364629, M/S 523
North Las Vegas, NV 89036-8629

SUBJECT: PRE-LICENSING EVALUATION OF UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS (USFIC) KEY TECHNICAL ISSUE (KTI) AGREEMENTS 4.02 AND 4.03

Dear Mr. Ziegler:

The U.S. Nuclear Regulatory Commission (NRC) has completed its evaluation of the U.S. Department of Energy's (DOE's) August 13, 2003, submittal on Key Technical Issue (KTI) Agreements Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 4.02 and 4.03. NRC found that the information provided in the USFIC 4.02 and 4.03 agreements response to be satisfactory. Therefore, NRC considers the agreements USFIC 4.02 and 4.03 complete.

With regard to USFIC Agreement 4.02, DOE agreed to consider the effect of the low-flow regime processes (e.g., film flow) or justify that it is not needed. For USFIC Agreement 4.03, DOE agreed to consider smaller scale tunnel irregularities in drift collapse or justify that it is not needed when conducting seepage studies. The technical information provided for the two agreements did not provide sufficient information to complete these agreement items. Instead, DOE relied on total-system sensitivity analyses to demonstrate that further reductions in uncertainties related to drift seepage will not significantly affect dose estimates from performance assessment calculations. Although the sensitivity analyses of seepage considered increased amounts of water at the location of the waste packages, a very small amount of this water contacted the waste form in the nominal scenario due to the presence of the drip shield and intact waste packages. Additionally, transport processes in the unsaturated and saturated zones limit the effects of releases due to potential increases in seepage. If DOE revises these important aspects of its performance assessment, the impacts on the sensitivity analyses of seepage would need to be determined. However, based on the considerations found in the attached review, NRC concludes that remaining uncertainties pertaining to the effects on seepage of small-scale tunnel irregularities and low-flow regime processes such as film flow in fracture networks do not significantly influence the total-system performance assessment analyses results. Consequently, the additional analyses and investigations requested in these agreement items are no longer necessary.

NRC's interest in the information requested in the agreements is to support a detailed review of a future license application. NRC will continue to consider risk information in conjunction with other factors when evaluating whether DOE has provided sufficient information for NRC to conduct a detailed review of a potential license application.

If you have any questions regarding this matter, please contact Gregory Hatchett, of my staff at 301-415-3315 or by e-mail to GXH@nrc.gov.

Sincerely,

/RA/

Janet R. Schlueter, Chief
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: NRC Review

cc: See attached distribution list

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Sincerely,

/RA/

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High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
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OFFICIAL RECORD

REVIEW BY THE OFFICE OF NUCLEAR MATERIAL SAFETY
AND SAFEGUARDS OF THE DEPARTMENT OF ENERGY'S
AGREEMENT RESPONSE RELATED TO THE PROPOSED GEOLOGIC REPOSITORY AT
YUCCA MOUNTAIN, NEVADA
"UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS" (USFIC)
KEY TECHNICAL ISSUE (KTI) AGREEMENTS 4.02 AND 4.03
[PROJECT NO. WM-00011]

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission's (NRC's) issue resolution goal during the 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 during pre-licensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. Also, and just as important, resolution of an issue by NRC during pre-licensing does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are resolved by the NRC during pre-licensing when the NRC 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.

By letter dated August 13, 2003, DOE submitted a report titled, "KTI Letter Report Response to USFIC 4.02 and 4.03," (Bechtel SAIC Company, LLC, 2003, ADAMS Accession No. ML032270386) to satisfy the informational needs of two Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) Key Technical Issue (KTI) Agreements, USFIC 4.02 and 4.03. Both of these agreements address DOE estimates of the amount of water that could potentially seep into repository drifts and contact drip shields or waste packages. NRC is concerned about the treatment of drift seepage processes in performance assessments because, should an aggressive corrosion environment or some disruptive event result in waste package failure, seepage water contacting the waste form would affect the release and transport of radionuclides. DOE considers that the NRC information needs regarding both agreements are fully addressed by the DOE response.

2.0 WORDING OF THE AGREEMENT(S)

NRC review of the DOE response to the subject agreements is based upon DOE providing the requested information identified in an NRC letter (Schlueter, 2000, ADAMS Accession No. ML003751891), which summarizes the USFIC Technical Exchange and Management Meeting held August 16–17, 2000. The agreements are as follows:

USFIC 4.02: "Include the effect of the low-flow regime processes (e.g., film flow) in DOE's seepage fraction and seepage flow, or justify that it is not needed. DOE will include the effect of the low-flow regime processes (e.g., film flow) in the seepage fraction and seepage flow, or justify that it is not needed. These studies will be documented in Seepage Models for Performance Assessment (PA) Including Drift Collapse Analysis Model Report (AMR) (MDL–NBS–HS–000002) expected to be available to NRC in FY 2003."

USFIC 4.03: "When conducting seepage studies, consider smaller scale tunnel irregularities in drift collapse, or justify that it is not needed. When conducting seepage studies, DOE will consider smaller scale tunnel irregularities in drift collapse, or justify that it is not needed. These studies will be documented in Seepage Models for PA Including Drift Collapse AMR (MDL–NBS–HS–000002) expected to be available to NRC in FY 2003."

3.0 SUMMARY OF INFORMATION PROVIDED IN THE DOE AGREEMENT RESPONSE

The DOE response (Adams Accession No. ML032270386) provides two types of information to address USFIC Agreements 4.02 and USFIC 4.03. First, DOE provides technical information to explain why drift seepage is treated appropriately in their total-system performance assessment analyses (Section 2.1). Second, DOE provides information, including dose-based risk assessments, to demonstrate the overall importance of seepage on the ability of a high-level waste repository to isolate waste (Sections 2.2, 2.3, and 2.4). NRC review of the DOE technical information and risk assessment analyses are summarized in the following sections.

3.1 Technical Information Provided by DOE

The technical information provided by DOE (Section 2.1.1) for USFIC Agreement 4.02 is a qualitative discussion of how film flow along drift walls might affect dripping of water from drift ceilings. No new information or analyses are provided to quantitatively assess the manner in which film flow in fracture networks might affect rates of dripping from drift ceilings. The discussion appears to consider film flow only in the context of water flowing down drift walls and does not mention potential effects of film flow that may occur on fracture surfaces within the fracture networks (i.e., water flowing in fractures that does not bridge the fracture aperture). Conditions that affect capillary diversion and dripping may be quite different for film flow than are currently modeled. The main assertion of the technical discussion is that seepage-relevant processes, including the seepage-reducing or the seepage-increasing impact of film flow, are inherently reflected in the amount of water collected during the *in-situ* field test used to develop the Seepage Calibration Model (CRWMS M&O, 2000a).

Technical information provided by DOE to address USFIC Agreement 4.03 suggests that small-scale roughness of the drift wall is implicitly accounted for by the 0.05-m [0.16-ft] model grid discretization, which does not allow horizontal flow diversion to occur closer than 0.05 m [0.16 ft] from the drift wall (Section 2.1.2). This modeling approach is documented in the analysis and model report for the Seepage Calibration Model (CRWMS M&O, 2000a).

DOE's response states that the combined effects of film flow and small-scale tunnel irregularities are taken into account in performance assessments by using a conservative approach in the engineered barrier system abstraction that assumes all dripping of drift seepage occurs from the drift crown above the waste package. That is, while some dripping might occur from one side or the other of the drift crown and thereby miss contacting a drip shield or waste package, DOE takes the conservative approach of assuming that the dripping will contact the engineered barrier system. It is stated that this approach ignores the potential for diversion of flow away from the drift crown in thin films on the drift walls, and that this approach effectively assumes that all irregularities for droplet formation are located at the drift crown.

3.2 Information Provided on Overall Importance of Seepage Issues to Waste Isolation

NRC, in a letter dated January 27, 2003, (Schlueter, 2003, ADAMS Accession No. ML030150051) identified three types of additional information necessary for a sufficiently developed risk argument to support closure of key technical issue agreements: (i) transparent and traceable documentation of analyses, (ii) presentation of the variability of results (as opposed to just mean results) from stochastic total-system risk analyses, and (iii) analyses of the effects of combined uncertainties. Sections 2.2, 2.3, and 2.4 of the response provide discussions and analyses of the overall importance of seepage issues to waste isolation to demonstrate that remaining uncertainties in the treatment of drift seepage do not significantly affect total-system performance calculations. Section 2.2 is a qualitative discussion of the role of seepage to waste isolation, both for nominally expected conditions and for disruptive conditions. Section 2.3 provides discussion of quantitative total-system sensitivity analyses, and Section 2.4 provides additional total-system analyses to demonstrate the effects of drift seepage when combined with uncertainties of several additional processes. Additionally, the DOE response contains appendices to provide transparency regarding changes in their performance assessment model that were made for the risk analyses. Brief summaries of the importance information provided by DOE are contained in the following subsections.

3.2.1 Description of Seepage Effects on Waste Isolation Capabilities

As conceptualized in the DOE nominal scenario, the overall importance of seepage is diminished because waste packages are expected to remain substantially intact and, in the event of waste package failure, intact drip shields would limit radionuclide releases to diffusive releases through the drift invert. Further, radionuclide solubility limits and waste form degradation rates act to limit the amount of release, even if seepage can come into contact with waste. For disruptive conditions, the role of seepage becomes more significant if the disruption results in failure of drip shields, waste packages, and spent fuel cladding. Such failures may occur, for example, as a result of an igneous intrusion.

Section 2.2.2 of the DOE response discusses the effects of seepage on the engineered system. For example, increased seepage could cause a larger fraction of drip shields or waste packages to be in an aqueous environment instead of just humid air. DOE points out, however, that studies show corrosion rates for Alloy 22 are similar for aqueous and humid air environments, implying that higher seepage would not substantially affect waste package lifetimes. Increased seepage could also change the chemistry of water contacting engineered components, but DOE maintains that drip shield or waste package degradation models, "…are calibrated to tests conducted over a range of environments, which were developed to bound in-drift chemical environments." DOE also cites sensitivity studies to suggest that the potential effects of increased seepage on waste form degradation and corrosion of spent fuel cladding does not play a significant role in total-system performance. DOE similarly cites sensitivity studies to suggest that effects of increased seepage on unsaturated zone radionuclide transport and diffusion through drift inverts would have little effect on mean dose estimates (see Sections 3.3.1 and 3.3.9). NRC evaluation and comments of the DOE description of the effects of seepage on waste isolation capabilities are provided in Section 4.2.1 of this review.

3.2.2 Transparent and Traceable Documentation Provided

Appendix A of the DOE response (Bechtel SAIC Company, LLC, 2003) provides a summary of the changes made to the performance assessment model for the seepage sensitivity studies. Similarly, Appendix B describes changes made to the performance assessment model to complete a combined uncertainty sensitivity study.

To accomplish the sensitivity studies, DOE made changes to the performance assessment model originally developed for the Final Environmental Impact Statement (FEIS). One significant change is that only 300 realizations were run for the igneous intrusion scenarios, compared to 5,000 realizations in the FEIS performance assessment model. In addition, compared to the FEIS model, the same radionuclide release curve was used regardless of when the igneous intrusion occurred. A third change is that the assumed number of initially failed waste packages from improper heat treatment was increased from 0.26 to 1.0 per realization to improve stability of mean dose estimates.

The seepage sensitivity studies for both nominal and igneous intrusion scenarios were conducted by setting the seepage rate through the drift to a value of 1.0 m^3/yr [264 gal/yr] per waste package and increasing the fraction of drifts that receive seepage to 100 percent. The combined effect of the changes was that, on average, the amount of water reaching waste packages was increased by a factor of 20 compared to the amount of seepage considered in the base case models. To be consistent with the assumed high seepage rates, the sensitivity studies were conducted using the unsaturated zone flow velocities obtained using the highest infiltration rates estimated for the glacial-transition climate state.

The results of these simulations show that differences in the probability-weighted mean annual dose curves for the base case model of the nominal scenario were negligibly affected by the substantial increase in assumed seepage rate. This result stems from the assumption that intact drip shields act to divert seepage from contacting the waste. Additionally, C-14, I-129, and Tc-99, which dominate the dose estimates, have high solubility limits; therefore, only small quantities of water are required to mobilize these radionuclides from the gradually degrading waste forms.

For the igneous intrusion scenario, generally higher mean dose estimates resulted from the assumed higher number of failed waste packages following the intrusion. Increased seepage in the igneous intrusion scenario resulted in an increase in the probability weighted mean annual dose estimate by as much as a factor of 20 during the first 3,000 years, but the highest dose estimates, between 4,000 years to the end of the 10,000-year simulation period, were only increased by approximately a factor of 5. The fact that the igneous intrusion scenario results were moderately sensitive to the increased seepage rate, and the nominal scenario results were not, is attributable to the assumption that the drip shields and waste packages are damaged in the igneous intrusion scenario, thus allowing advective transport of radionuclides from the waste form. For the igneous intrusion scenario, the dominant radionuclides were Np-237, Pu-239, and Pu-240, which have low solubility limits. More seepage contacting the degraded waste allows a greater mass of these radionuclides to be mobilized. It should be noted, however, that the peak mean annual dose increases to less than 0.02 mrem [0.0002 mSv] for the high-seepage igneous intrusion case, which is only a small fraction of the regulatory individual dose standard of 15 mrem [0.15 mSv].

3.2.3 Information Provided on Variability of the Results

NRC requested that the DOE provide information pertaining to the variability in the results of the sensitivity studies when providing information in lieu of the technical information outlined in an agreement. Figure 1 of the DOE response shows mean annual dose curves for the 10,000-year period, as well as the 5^{th} and 95^{th} percentile curves for both the nominal and igneous intrusion modeling scenarios with base case infiltration rates. Additionally, Figure 3 of the DOE response shows the effect on the 95^{th} percentile curves after changing from the base case seepage rates to the case with 1.0 m^3/yr [264 gal/yr] per waste package. This figure shows that, when increased seepage is assumed, the 95^{th} percentile dose curve changes significantly (by approximately a factor of 20) only for the igneous intrusion modeling case.

3.2.4 Information Provided on the Combined Effects of Uncertainty

Section 2.4 of the DOE response provides a summary of a combined effects sensitivity study originally documented in "Risk Information to Support Prioritization of Performance Assessment Models" (Bechtel SAIC Company, LLC, 2002, Section 3.4). The combined effects study was presented because the one-off sensitivity studies discussed above in Section 3.2.3 may not fully address the importance of uncertainties in the seepage model when considered in combination with other uncertainties. DOE emphasized that uncertainty importance analyses consistently show that the uncertainties dominating the variance in the estimates of total system performance are those related to waste package performance. Uncertainties in the seepage model, however, may be of increased significance when combined with uncertainties in other performance assessment model components.

The combined effects sensitivity study reported the results of considering the combined effect of changes to the probability models for several performance assessment model components. DOE indicated that the combined effects analysis included changes to models that will not be included in sensitivity analysis used to address other key technical issue agreements (e.g., waste package degradation). The study evaluated the importance of simultaneous changes to the following performance assessment model components:

- Mean infiltration rate
- In-drift chemistry
- Waste package degradation
- In-package chemistry
- Commercial spent nuclear fuel cladding performance
- Dissolved radionuclide concentration limits
- Colloid-associated radionuclide concentrations
- Unsaturated zone radionuclide transport

DOE provided general descriptions of the changes made to each model component, and Appendix B of the DOE response contains a listing of specific changes to the GoldSim file used in the simulation. DOE states that, in general, the changes to the respective performance assessment model components represent reasonable bounds or, in some cases, parameter values that are well outside of the range of uncertainty in the base case model. The estimate of mean annual dose generated from the combined effects study and provided in Figure 4 remains below the regulatory limit of 15 mrem [0.15 mSv] for both the igneous intrusion case {0.9 mrem/yr [0.009 mSv]} and the nominal scenario {0.1 mrem/yr [0.001 mSv]} for 10,000 years. DOE concluded that the uncertainties in the seepage model are not likely to combine with uncertainties in other performance assessment model components to result in an estimate approaching the regulatory standard.

4.0 NRC EVALUATION AND COMMENTS

Agreements USFIC 4.02 and USFIC 4.03 are pertinent to understanding the extent to which film flow in fracture networks and accumulation of water on small-scale drift asperities may affect the amount of water that may drip onto drip shields or waste packages and whether it is necessary to consider such effects in performance assessments of the proposed repository. The information provided by DOE has been reviewed in that context.

4.1 NRC Evaluation and Comments on the Technical Information Provided

4.1.1 Technical Information Provided for Agreement USFIC 4.02

The technical information provided for Agreement USFIC 4.02 is focused mainly on the potential effects of film flow down drift walls, whereas the original NRC staff concern was that, under low-flow conditions, film flow can occur on fracture surfaces within fracture networks. Because film flow on fracture faces does not bridge fracture gaps, staff were concerned that the conceptual model of capillary retention of water in fracture networks at the drift interface and the subsequent diversion of water around drifts may not be valid for low-flow regimes. Hence, it is conceivable that dripping could occur above many more waste packages, albeit at very low rates, than is currently accounted for in DOE performance assessments. Because *in-situ* seepage tests (CRWMS M&O, 2000a) were conducted at relatively high flow rates, on a small scale and almost certainly were affected by dryout from ventilation, staff were concerned that the potential for dripping during low ambient flows in an unventilated environment was not adequately represented in the DOE Seepage Calibration Model (CRWMS M&O, 2000a) or in the Seepage Model for Performance Assessment (CRWMS M&O, 2000b). These staff concerns are not addressed by the technical information provided by DOE in response to Agreement USFIC 4.02. That is, no new information or analyses are provided to assess the contribution of film flow or other low-flow processes to dripping from drift ceilings.

4.1.2 Technical Information Provided for Agreement USFIC 4.03

Technical information provided to address Agreement USFIC 4.03 suggests that small-scale roughness of the drift wall is implicitly accounted for by the 0.05-m [0.16-ft] model grid discretization, which does not allow horizontal flow diversion to occur closer than 0.05 m [0.16 ft] from the drift wall. This assertion is documented in the analysis and model report for the Seepage Calibration Model (CRWMS M&O, 2000a), which was to estimate hydrologic parameters for an *in-situ* seepage test. It should be noted, however, that the Seepage Calibration Model was only one of several sources used to determine the range of hydrologic parameters considered in the Seepage Model for Performance Assessment (CRWMS M&O, 2000b). In the Seepage Model for Performance Assessment, a model grid discretization 10 times larger than in the Seepage Calibration Model was used, and the model documentation (CRWMS M&O, 2000b) does not mention how lateral flow is treated in grid cells adjacent to the drift wall in the Seepage Model for Performance Assessment. It is thus not clear to NRC that the Seepage Model for Performance Assessment accounts for the effects of small-scale tunnel irregularities in the manner described in the DOE response to Agreement USFIC 4.03.

4.1.3 Additional Considerations

Since the time of the original USFIC 4.02 and USFIC 4.03 agreements, some recent observations and analyses have somewhat mitigated the original staff concerns related to the potential for dripping during low-flow ambient conditions. First, DOE has been conducting long-term observations of seepage under ambient flow conditions in unventilated sections of the Enhanced Characterization of the Repository Block tunnel and in Alcove 7. It can be seen in photographs from unventilated entries into these study areas that fracture networks are actively conducting unsaturated flow around drift openings and there have been few observations of dripping that can be directly attributed to fracture flow intersecting drifts. It also appears from these studies that condensation of moisture vapor on ventilation ducts and utility lines may be a far more important process that can lead to dripping. Observations from the unventilated drift studies remain to be formally documented (as per Agreement USFIC 4.01), however, NRC interpretations of such observations may change as more information becomes available.

Another development that mitigates staff concerns pertaining to the subject agreements is that recent staff analyses show repository drifts degrading and becoming filled with rockfall rubble within several hundred years after permanent closure (Gute, et al., 2003). If such a natural backfilling process occurs relatively early in the 10,000-year compliance period, other issues of concern would need to be addressed; however, staff concerns regarding small-scale irregularities or low-flow processes at the drift wall may be irrelevant in such a drift environment.

4.2 NRC Evaluation and Comments on Information Provided on Overall Importance of Seepage Issues to Waste Isolation

4.2.1 Evaluation and Comments on Effects of Seepage on Waste Isolation Capabilities

DOE provides useful information pertaining to the role of drift seepage on the waste isolation capabilities of natural and engineered barriers. However, significant conceptual uncertainties remain regarding the complex processes that might affect the chemistry of seepage water and the resulting effects on corrosion rates for drip shields and waste packages. These processes may be sensitive to low flow rates of seepage and are not understood sufficiently to provide confidence in conclusions that increased seepage would have either minimal or beneficial effects on corrosion rates. Other key technical issue agreements, such as Evolution of Near Field Environment (ENFE) 2.06 and 2.09, are focused on obtaining a better understanding of the potential range of local chemical conditions that may occur on drip shield and waste package surfaces.

DOE cites sensitivity analyses to suggest several processes, such as waste form degradation, corrosion of spent fuel cladding, diffusion through inverts, and radionuclide transport in the unsaturated zone, do not have a significant effect on mean dose estimates from total-system performance calculations. It is thus inferred that the effects of increased seepage on these processes should also have little effect on mean dose estimates, but none of the cited sensitivity analyses provide direct assessment of the degree to which increased seepage might affect the processes evaluated in the sensitivity studies. However, most of these processes (except for invert diffusion rates) were conservatively bounded in the combined effects analyses provided in the DOE response, which provides an assessment of the sensitivity of mean annual dose estimates to increased seepage when several barrier components are simultaneously treated in a conservative or bounding manner.

4.2.2 Evaluation and Comments on Transparent and Traceable Documentation Provided

The information provided by DOE contains sufficient detail to allow NRC to understand the changes made to the performance assessment model for the seepage sensitivity studies. In particular, the seepage rate was increased to 1.0 m^3/yr [264 gal/yr] and applied to every waste package location, compared to the DOE's stated base case nominal scenario with zero seepage over approximately half of the repository area and spatially variable seepage that averages approximately 0.1 m^3/yr [26 gal/yr] where seepage does occur. However, NRC was not able to obtain the same seepage flow rate as stated in the DOE response report. Using the information found in Bechtel SAIC Company, LLC (2001a), a weighted average seepage flow of 0.37 m^3/yr [98 gal/yr] was discerned for 48% of the waste package locations during the nominal scenario at 10,000 years postclosure. The bounding seepage flow of 1.0 m^3/yr [264 gal/yr] for each waste package location would be greater by a factor of 5.4 than the base case nominal scenario, compared to a factor of 20 as stated in the response report. Appendix A of the DOE response provided a summary of the general changes to the performance assessment model, as well as specific changes to parameter distributions. This level of detail is sufficient to allow independent verification by NRC of the changes made to the DOE performance assessment model.

Compared to the performance assessment model for the FEIS, the seepage sensitivity study presented in the DOE response used fewer stochastic realizations for the igneous intrusion scenario (300 compared to 5,000). Probabilistic analyses used to make regulatory decisions must be based on a sufficient number of realizations to ensure numerical stability of the peak mean dose (consistent with Agreement Total System Performance Assessment and Integration (TSPAI) 4.03). The DOE response cites Figure 2 of Bechtel SAIC Company, LLC (2002), which provides a comparison of the results for the igneous intrusion scenario using 5,000 and 300 realizations. There is a relatively minor difference in the output, indicating that the dose estimates should remain stable with the fewer number of realizations.

A second change from the FEIS model is that the same release function to represent release of waste from the engineered barrier system was used to represent system performance regardless of when the igneous intrusion occurred. This approach is reasonable to reduce the complexity in the sensitivity studies; however, it may not fully capture early (e.g., less than 2,000 years) temperature effects related to waste form dissolution under different performance assessment model conditions. Figure 3 in Bechtel SAIC Company, LLC (2002) is referenced to show that the method provides similar results to the base case performance assessment for the FEIS.

A third change from the FEIS model is that the assumed number of initially failed waste packages from improper heat treatment was increased to 1.0 per realization (from the nominal scenario fraction of 0.26) to improve stability of mean dose estimates. This addition of conservatism to simplify the analysis is acceptable for the purpose of sensitivity analyses. In this case, it would be expected that the nominal scenario expected dose estimates are higher by approximately a factor of four compared to the FEIS model.

For the seepage sensitivity study comparing the base case seepage to a bounding seepage case, NRC agrees with DOE's application of a seepage rate of 1.0 m^3/yr [264 gal/yr] to every waste package location as an acceptable upper bound on the amount of water likely to contact the engineered system under most circumstances. This seepage rate equates to a flux of at least 60 mm/yr [2.4 in/yr] over the footprint area of a drip shield. Percolation rates of this magnitude could occur locally in areas where focusing of flow may occur, but it is conservative to consider that every waste package location could receive this much dripping for the entire 10,000-year compliance period. Contributions to seepage flux from low-flow regime processes or small-scale drift asperities would likely constitute only a small fraction of such a high flow.

It should be noted that the difference in peak mean annual dose between the igneous intrusion scenario with base case seepage and with high seepage (approximately a factor of 5) is not directly proportional to the increase in the amount of water flow (approximately a factor of 20 as stated by the DOE). However, if the increase in the amount of bounding seepage flow is 5 times higher than the base case seepage, as calculated by the NRC, the difference in peak mean annual dose between the two cases of the igneous intrusion scenario is approximately proportional.

Transparency of these analyses and their accompanying conclusions could be improved by an explanation of this model result—for example, through the presentation of intermediate outputs, or by stating that it would only take the equivalent of X amount of water entering a package to mobilize the Tc-99 released from the waste forms each year. In particular, transparency of output results is lacking for the igneous intrusion scenario. However, DOE’s response indicated that the impacts on risk from release of these radionuclides are limited by the following:

- The low probability that the disruptive conditions occur;

- The total amount of water contacting the waste, which cannot be greater than the maximum amount of precipitation that might fall onto Yucca Mountain over that period in the event the disruptive event occurs; and

- Risk is limited by the performance of the unsaturated zone and the saturated zone flow and transport barriers that continue to limit the amount of radionuclides that can reach members of the public even in the event of the igneous intrusion

Marginal justification is provided to support the limiting factors and few insights as to how the radionuclides are being retarded are gained. DOE’s response should have included additional justification to provide the clarity needed to fully understand the processes related to the limiting factors.

4.2.3 Evaluation and Comments on Variability of the Results Provided

Figure 3 of the DOE response shows changes to the 95th percentile of the annual dose estimates for the seepage sensitivity study. It is recommended that future reports to resolve key technical issue agreements with risk assessment analyses also provide a similar presentation of the 5th percentile curves. In the case of water flow contacting waste, releases from the engineered barrier system can be sensitive to reductions in the amount of water available to mobilize waste. The peak mean dose can be relatively insensitive to increases in the amount of water contacting waste. However, because of the solubility limits of key radionuclides and the potential for the waste form water contact mode to create a delay in release of radionuclides, peak mean dose can be sensitive to decreases in the amount of water contacting waste. Presentation of the 5th percentile curves would provide staff with information to assess the relative effects of decreases in water contacting waste; however, this information is not considered critical for closure of the subject agreement items.

4.2.4 Evaluation and Comments on Information Provided on the Combined Effect of Uncertainty

NRC requested DOE to assess the combined effects of uncertainty. In particular, the combined effect of uncertainties (for all agreements being addressed with dose-based sensitivity arguments) needs to be evaluated before the individual uncertainties can be dropped from further consideration. Otherwise, a situation could arise where moderate increases in risk are considered insignificant but, when numerous uncertainties are addressed in this manner, the combined effect could be significant.

Results from the DOE sensitivity study of combined effects of uncertainty showed increases in peak mean annual dose to 0.1 mrem [0.001 mSv] for the nominal scenario, and to 0.9 mrem [0.009 mSv] for the igneous intrusion scenario. This result demonstrates that uncertainty in drift seepage estimates, when conservatively bounded and combined with several other process uncertainties, does not result in mean annual dose estimates that exceed regulatory dose limits during the 10,000-year simulation period. DOE has provided risk assessment analyses to support completion of USFIC Agreements 4.02 and 4.03. Further, for other agreements that may be addressed with risk information in lieu of the originally requested information, DOE will need to provide a basis to justify that the uncertainty is reasonably bounded in risk sensitivity analyses that include the cumulative effects of uncertainties related to all of the agreements intended to be completed using risk information.

5.0 SUMMARY

The technical information provided for USFIC Agreements 4.02 and 4.03 does not provide sufficient information to complete these agreements. However, DOE's response relies on total-system risk sensitivity analyses to demonstrate that further reductions in uncertainties related to drift seepage would not significantly affect dose estimates from performance assessment calculations.

NRC agrees that the use of an assumed seepage rate of 1.0 m^3/yr [264 gal/yr] on every waste package in risk sensitivity analyses is an acceptable upper bound on the amount of water likely to contact the engineered system under most circumstances. The contribution of low-flow regime processes and small-scale tunnel asperities to the total amount of dripping from drift ceilings would likely constitute only a small fraction of such a high seepage rate, which is a key aspect for resolving these agreement items. The relatively incremental amount of uncertainty in the seepage processes related to the specific agreement items are shown not to be of high risk significance in the context of the total-system. This conclusion is consistent with an NRC preliminary analysis that suggest the issue of seepage into repository drifts is of "medium risk significance" (Travers, 2003).

The DOE risk sensitivity studies presented in the response show that increased seepage rates significantly affect mean annual dose estimates only when some type of disruptive event (e.g., an igneous intrusion) occurs that results in removal of drip shields and rapid failure of waste packages. It should be noted that the difference in peak mean annual dose between the igneous intrusion scenario with base case seepage and with high seepage is directly proportional to the increase in the amount of water flow (approximately a factor of 5) at 10,000 years postclosure. However, the calculated mean and 95th percentile dose estimates remained well below the 15 mrem [0.15 mSv] regulatory individual dose standard, even when combined with several additional parameter uncertainties. Multiple barriers help keep the mean annual dose estimates for the bounding seepage sensitivity studies low. Drip shield, waste package, and other engineered barrier system components are effective barriers for the nominal scenario, while matrix diffusion and retardation in the unsaturated and saturated zones are effective processes in delaying transport for both the nominal and the igneous intrusion scenarios.

During the NRC's review of the risk information provided by DOE in response to the agreements, NRC observed that the risk information provided for these agreements was generated by a performance assessment model similar to the model used for the Final Environmental Impact Statement. The performance assessment supporting a potential license application may be significantly different than the models used in the DOE response to these agreement items. The final, fully-qualified performance assessment used for a potential license application would have to include a confirmatory analysis. In addition, NRC noted that DOE focused only on the ability of the total system to meet the individual dose protection standard, and no information was given about the ability to meet groundwater protection standards. A demonstration of the ability to meet groundwater protection standards, considering the same uncertainties recognized in the individual dose calculations, should be provided in any future license application. Further, the conclusions drawn from total-system performance results of the dose-based, sensitivity analyses are for two scenarios (nominal and igneous intrusion) only. Future scenarios not excluded from a potential license application such as a partial or total drift degradation scenario, should be included in the risk assessment analyses. Finally, ongoing data collection and analyses to address key technical issue agreements USFIC 4.01, Evolution of the Near Field Environment 2.06 and 2.09 could provide new insights pertaining to the overall importance of seepage estimates to total-system performance. This new information could result in NRC needing additional information regarding the effects of low-flow processes, small-scale irregularities, or other processes.

Although the sensitivity analyses of seepage considered increased amounts of water at the location of the waste packages, a very small amount of this water contacted the waste form in the nominal scenario due to the presence of the drip shield and intact waste packages. Additionally, transport processes in the unsaturated and saturated zones limit the effects of releases due to potential increases in seepage. If DOE revises these important aspects of its performance assessment, the impacts on the sensitivity analyses of seepage would need to be determined. However, based on the above considerations, NRC found that the remaining uncertainties pertaining to the effects on seepage of small-scale tunnel irregularities and low-flow regime processes such as film flow in fracture networks are not sufficiently important to total-system performance assessment calculations to warrant the additional analyses and investigations requested in the agreement items.

6.0 STATUS OF THE AGREEMENTS

Notwithstanding new information that could raise new questions or comments concerning USFIC Agreements 4.02 and 4.03, based upon the above review, NRC agrees with DOE that the information provided satisfies the intent of the agreement items. Therefore, the NRC considers USFIC Agreements 4.02 and 4.03 complete, and NRC has no further questions at this time.

7.0 REFERENCES

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