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TRANSMITTAL OF REPORT ADDRESSING KEY TECHNICAL ISSUE (KTI) AGREEMENTS UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS (USFIC) 4.02 AND 4.03

References: (1) Ltr, Williams to Ziegler, dtd 1/30/03
(2) Ltr, Schlueter to Ziegler, dtd 1/27/03
(3) Ltr, Schlueter to Ziegler, dtd 5/9/03

This letter transmits a letter report entitled *KTI Letter Report, Response to USFIC 4.02 and 4.03*, REG-WIS-PA-000002, Revision 01, ICN 05, which provides the basis for closure of the subject KTI agreements. The agreements read as follows:

> USFIC 4.02: "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.
> 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 PA Including Drift Collapse 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."

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Recent Total System Performance Assessment (TSPA) sensitivity studies, combined with the physical understanding of seepage into emplacement drifts, show that the treatment of uncertainty in these processes is sufficiently robust, and that the information requested by the KTI agreements would not change the determination of whether or not the individual protection or groundwater protection standards of 10 CFR Part 63 would be met. In particular, the potential effects of film flow or small-scale asperities on seepage do not play a significant role in determining the potential dose, even when maximum plausible seepage rates are input to model calculations.

While the technical information requested by the U.S. Nuclear Regulatory Commission (NRC) may add to the technical basis underlying the models for seepage in emplacement drifts, the U.S. Department of Energy (DOE) believes the current representation of seepage is adequate for evaluating compliance with the regulatory requirements of 10 CFR Part 63. The enclosed KTI letter report provides risk information, along with a discussion of the physical understanding of seepage processes and test results, to address KTI Agreements USFIC 4.02 and 4.03.

During preparation of this letter report, NRC requested that specific information be provided in any risk-informed approach to the resolution of KTI agreements (Reference 2). The requested information includes:

- Transparent and traceable documentation that allows results of analyses of impacts on risk estimates to be verified independently
- Information pertaining to variability of the results
- Consideration of the combined effect of uncertainties

The enclosed letter report includes information to address these recommendations. Appendices A and B provide a description of the specific changes to the TSPA model that were made to implement the relevant sensitivity studies. These appendices also provide sufficient information for independent verification of the risk analyses. To address variability of the results, the letter report includes the 95th percentile results of the probabilistic analyses conducted for the sensitivity study. Section 2.2.1 includes a discussion of how the various barriers are expected to perform together under expected conditions. Section 2.2.2 summarizes how the various barriers might be affected if the issues identified in the agreement result in higher levels of seepage than in the TSPA model. Section 2.4 addresses the combined effects of uncertainty.

In addition to requesting the above information, NRC has suggested, in recent responses to risk-informed KTI letters, that the DOE update its total system sensitivity analyses for the nominal scenario for the groundwater protection standards (see Reference 3 for an example). Previous TSPAs have shown that factors affecting groundwater concentrations of radionuclides released from the repository are the same as those affecting the estimated mean annual dose.

Conclusions drawn from the sensitivity studies regarding the mean annual dose should be indicative of the conclusions regarding groundwater concentrations; therefore, these additional sensitivity studies are not necessary to address these KTI agreements.

The DOE considers Agreements USFIC 4.02 and 4.03 to be fully addressed by the enclosed letter report and, pending review and acceptance by the NRC, these agreement items should be considered closed.

There are no new regulatory commitments in the body or enclosure to this letter. Please direct any questions concerning this letter and its enclosure to Eric T. Smistad (702) 794-5073 or Carol L. Hanlon at (702) 794-1324.

Joseph D. Ziegler, Acting Director
Office of License Application and Strategy

OLA&S:TCG-0620

Enclosure:
KTI Letter Report, Response to USFIC 4.02 and 4.03, REG-WIS-PA-000002, Revision 01, ICN 5

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REG-WIS-PA-000002 REV 01 ICN 05

July 2003

KTI Letter Report
Response to USFIC 4.02 and 4.03

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Under Contract Number
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ENCLOSURE

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

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CHANGE HISTORY

Revision Number	Interim Change No.	Date of Revision	Description of Change
0	0	01/22/03	Initial issue for DOE review.
1	0	03/25/03	Changes to address DOE Acceptance Review comments, including comments regarding NRC January 27, 2003 recommendations for letter reports providing risk information to address KTI agreements. No change bars shown.
1	1	03/27/03	Editorial changes identified during the DOE-NRC teleconference on 3/27/03. No change bars shown.
1	2	05/06/2003	Changes in response to additional LAP comments. No change bars shown.
1	3	07/23/03	Changes to provide discussion of groundwater protection standards, consistency with barrier importance arguments, and combined effects sensitivity studies. No change bars shown.
1	4	7/28/03	Editorial changes to Table of Contents and page 13, #6. No change bars are shown.
1	5	7/30/03	Editorial change near the top of page 13. No change bar shown.

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CONTENTS

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FIGURES

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ACRONYMS

BSC	Bechtel SAIC Company, LLC
CRWMS M&O	Civilian Radioactive Waste Management System Management & Operating Contractor
DOE	U.S. Department of Energy
EBS	engineered barrier system
KTI	Key Technical Issue
NRC	U.S. Nuclear Regulatory Commission
TSPA	total system performance assessment
USFIC	Unsaturated and Saturated Flow under Isothermal Conditions

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ACKNOWLEDGMENT

The contributions of the Natural Systems Project to Section 2.1 and the Natural Systems and Engineered Systems Projects to Section 2.2 are acknowledged.

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1. INTRODUCTION

1.1 BACKGROUND

This letter report addresses Key Technical Issue (KTI) agreements Unsaturated and Saturated Flow under Isothermal Conditions (USFIC) 4.02 and 4.03. These agreements between the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) read as follows (NRC 2002, p. A-36):

- **USFIC 4.02**: "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. 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 PA Including Drift Collapse 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."

These KTI agreements pertain to the technical basis for the representation of seepage into the tunnels. The specific issues underlying these agreements are summarized in the NRC's *Integrated Issue Resolution Status Report* (NRC 2002, Section 3.3.6.4). In that report, the NRC comments that the list of features, events, and processes that need to be incorporated into the model might include film flow occurring under low fluxes. The NRC also comments that the effects of small-scale irregularities, such as those that might arise from drift degradation, could lead to underpredictions of seepage into the emplacement drifts. The combination of these two effects, film flow along drift walls and small-scale asperities, could result in increased local dripping onto the drip shield or into the drift invert.

During preparation of this letter report, the NRC requested (Schlueter 2003a) that particular information be provided in any risk-informed approach to resolution of KTI agreements. This information includes the following:

- Consideration of the combined effect of uncertainties

- Transparent and traceable documentation that allows results of analyses of impacts on risk estimates to be verified independently

- Information pertaining to variability of the results.

1.2 PROPOSED RESOLUTION

These KTI agreements pertain to the technical basis and details of the representation of seepage into the emplacement drifts in the total system performance assessment (TSPA) model. The

technical basis for this representation was provided in the suite of Site Recommendation documents and will be updated in the suite of License Application documents. The information called for in these agreements would increase understanding prior to the License Application, in particular with respect to the effects of film flow in the low-flow regime and with respect to the effects of tunnel irregularities such as those associated with drift degradation.

Since these agreements were made, a TSPA sensitivity study has been conducted that provides additional insight into the significance of the uncertainty in the seepage representation. In particular, this study shows that the uncertainties in the current representation of seepage (e.g., those that might arise from film flow effects and the effects of small-scale tunnel irregularities) are not sufficient to affect assessment of compliance with the individual and groundwater protection requirements of 10 CFR 63.113 or the description of barrier capabilities required by 10 CFR 63.115. The results of this sensitivity study therefore provide additional information, not available at the time of the KTI agreements, that is relevant to the technical basis for the seepage model in the areas addressed by these KTI agreements.

Consistent with a risk-informed approach to resolution of issues, information to satisfy these agreements is provided in four areas. First, information is provided that directly addresses the questions of the technical basis for the seepage model identified in these specific agreements. Second, the specific effects on the combined capabilities of repository barriers to limit movement of water or radionuclides are discussed. Third, the sensitivity of quantitative estimates of total system performance (i.e., estimates of mean annual dose) to uncertainties in seepage into the emplacement drifts has been calculated. Fourth, the combined effects of varying input parameters are calculated to establish the impact of multiple changes to the TSPA model. The information in these areas augments the technical basis existing at the time the respective agreements were made.

The issues that are the subject of these KTI agreements are discussed in Section 2.1. This summary specifically addresses the issues raised regarding film flow in the low-flow regime and regarding small-scale tunnel irregularities. The relationship of these issues to the capabilities of the repository barriers is discussed in Section 2.2. In Section 2.3, the sensitivity of the estimate of mean annual dose to uncertainties in the seepage model, including those associated with the treatment of film flow and small-scale tunnel irregularities, is assessed through a TSPA sensitivity study to confirm the qualitative understanding provided in Section 2.2. The results of the combined effects sensitivity study are discussed in Section 2.4.

This letter report provides information to address recommendations the NRC has made with regard to a risk-informed approach to resolution of KTI agreements (Schlueter 2003a). In particular this information includes the following:

Consideration of the combined effect of uncertainties. This letter report includes a summary in Section 2.4 of the multiple changes that were made to the TSPA in implementing the combined effects sensitivity study presented in the *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002).

Transparent and traceable documentation that allows results to be verified independently. This letter report includes an explicit description of the specific changes to the TSPA model that

were made in implementing the relevant sensitivity studies. This information, including formats required for duplicating model results, is provided in Appendices A and B.

Information pertaining to variability of the results. In addition to the results of the sensitivity study regarding estimates of mean annual dose, the information provided to address the KTI agreements includes the 95th percentile results of the probabilistic analyses conducted for the sensitivity study. This information is provided in Section 2.3.

The considerations in this paper focus on estimates of mean annual dose, the measure of performance applicable to the individual protection standards. In addition to requesting the above information, the NRC has recommended, in recent responses to risk-informed KTI letters (Schlueter 2003b, Schlueter 2003c), that DOE update its total-system sensitivity analyses for the nominal scenario with regard to the groundwater protection standards. Previous TSPA analyses (BSC 2001a, Figures 4.1-16 and 4.1-17) have shown that the groundwater protection standards are expected to be met. The factors affecting groundwater concentrations of radionuclides released from the repository are the same as those affecting the estimate of mean annual dose for the nominal scenario, so that conclusions drawn from the sensitivity studies regarding mean annual dose should be indicative of the conclusions regarding these groundwater concentrations. The update to groundwater protection analyses will be provided in the TSPA-LA.

2. TECHNICAL BASIS FOR THE PROPOSED RESOLUTION

The seepage model is used to generate the representation of moisture entering the emplacement drifts above the invert. Moisture condensing within the drifts or waste packages, and moisture imbibing into the invert directly from the host rock, are calculated using other models. Seepage can potentially affect the estimated amount of water that might contact engineered barriers and mobilize radionuclides. Additionally, seepage could affect transport of radionuclides out of the waste packages and down through the drift invert to the unsaturated rocks below the repository. Therefore, the seepage model needs to be taken into account in the assessment of potential migration of radionuclides and concentrations of radionuclides in groundwater. Accordingly, the issues associated with the uncertainty in this model relate directly to whether the model is adequate to support determination of compliance with the individual and groundwater protection standards.

2.1 ISSUES REGARDING THE CURRENT TECHNICAL BASIS

2.1.1 Effects of Film Flow on Seepage Estimates

The overall testing and modeling approach used to estimate seepage into waste emplacement drifts implicitly captures the effects of film flow on the predicted fraction of drift length experiencing seepage and on the seepage rate into those locations. While film flow is not explicitly included in the model (i.e., no equation governing film flow is solved) and is thus not directly quantified, its impact on seepage is appropriately captured through the estimation of an effective capillary-strength parameter. The justification for the inclusion of film flow in an effective capillary-strength parameter is discussed in detail in *Seepage Calibration Model and Seepage Testing Data* (CRWMS M&O 2001a, Section 6.3.3). The approach is summarized in the following discussion.

Seepage above the invert into the emplacement drifts is defined as flow of liquid water from the host rock into the drifts. Under unsaturated conditions, percolation water approaching the drift may be diverted around the opening because of capillary action by the small pores of the host rock. However, conditions in the rock such as flow focusing or changes to drift crown geometry (from rockfall degradation) may result in a local increase in saturation near the drift wall surface and result in water exiting the formation. This water may form a drop that grows and eventually detaches under the influence of gravity. Only this last mechanism is considered drift seepage according to the definition above.

Seepage would be decreased if the water does not detach, but evaporates or flows as a film along the inclined drift surface and does not actually drip into the drift opening. Water flowing in the film could end up as seepage if it reaches topographic lows along the drift ceiling and accumulates into a drop that eventually detaches. Explicitly simulating the processes of evaporation, film flow along a rough drift surface, accumulation in topographic troughs, drop formation, and drop detachment is not feasible, due to computational limitations and also because of a lack of data at the small scales needed to characterize these processes. However, all these effects can be active in liquid-release tests. Such liquid-release tests have been conducted in niches and in the Enhanced Characterization of the Repository Block cross drift. The underground openings exhibit rough wall surfaces and other smaller scale irregularities (such as those resulting from the presence of lithophysal cavities). Spreading of water along the drift surface, eventually initiating seepage, has been observed and documented in *In Situ Field Testing of Processes* (BSC 2001b, Section 6.2.1.3.4 and Figure 6.2.1-7) and by Trautz and Wang (2002, Figures 7 and 9). The seepage water collected in the capture system inherently reflects the seepage-relevant processes (including the seepage-reducing or seepage-increasing impact of film flow).

The seepage rate data are used to calibrate the seepage model. A capillary-strength parameter is determined that appropriately incorporates the water-release seepage test results and takes into account the portion of the injected water that is realized as seepage (reproducing the measured data). The model also provides estimates for the amounts of water evaporated, stored in the formation, and diverted around the drift. The latter amount includes the water that is diverted around the drift in a thin film within the first element of rock beyond the drift wall. The contribution of film flow to the overall mass balance under steady-state conditions, in relation to seepage, is largest for percolation fluxes near the seepage threshold. These are the conditions encountered during the liquid-release tests, where water was injected above and below the seepage threshold. The resulting effective parameters, which are used for the prediction of seepage into waste emplacement drifts, thus incorporate film flow effects over a range of flux conditions that spans above-threshold and below-threshold (low) flux regimes. Seepage predictions made with the model therefore appropriately capture film flow effects over this range.

2.1.2 Effects of Small-Scale Tunnel Irregularities on Seepage Estimates

Breakouts in the drift ceiling resulting from rockfall or general drift degradation may change the overall drift geometry and lead to local topographic lows, which may trap water and reduce or prevent flow diversion. These geometric details could affect the estimate of seepage. In addition, small-scale surface roughness may increase seepage if the amplitude of the irregularity

is on the order of the boundary layer thickness where flow diversion occurs. The latter is determined by the capillary strength of the formation.

As discussed above, the seepage predictions are based on a process model that is calibrated with experimental data. The measurements of seepage into niches account for medium-scale roughness from rockfall and large lithophysal cavities. In addition, small-scale roughness is implicitly accounted for in the discretization of the numerical model. The length of the last vertical connection from the grid blocks representing the formation and the interface denoting the drift surface is 0.05 m. The choice of this nodal distance affects the estimate of seepage because horizontal flow diversion occurring closer than 0.05 m from the drift wall is not taken into account. Since water is laterally diverted only if capillary suction is on the order of 0.05 m or higher, the discretization effectively accounts for drift wall roughness of amplitude of 0.05 m and less, and short fractures that are separated by less than 0.05 m.

2.1.3 Effects on Estimates of Seepage Contacting Engineered Barriers

The potential for low-flow regime processes and the presence of possible tunnel irregularities are also considered in the flow abstraction for the engineered barrier system (EBS). The EBS flow abstraction is concerned with the potential for diversion of seepage by the drip shield and waste package, and is independent of the seepage abstraction that defines the incoming flux of liquid entering a drift above the invert. The EBS flow abstraction assumes that all seepage falls as droplets from the crown of the drift. This approach is conservative for an intact drift because it ensures that all the incoming seepage flux falls on the center of the drip shield without diversion due to lateral flow around the drift and without loss from evaporation. This approach is also conservative for a degraded drift, where rockfall alters the circular shape of the drift.

The rationale for this approach is as follows:

- It is conservative to ignore the potential for diversion of flow in thin liquid films on the walls of the drift. The presence of thin liquid films enhances the potential for evaporation of liquid from the drift walls, thereby reducing the potential for liquid flux onto the drip shield. In addition, the potential for lateral flow of a thin film can divert liquid drops to fall toward the outside of the drip shield or even completely beyond the drip shield, depending on the location of irregularities that trigger droplet formation. This lateral diversion can reduce the flux that passes through a breached drip shield if the droplets hit below the breaches or miss the drip shield entirely.

- It is also conservative to assume that all irregularities for droplet formation are located at the crown of the drift. Irregularities would actually be distributed across the drift surface, resulting in a distribution of flux, some of which could miss the drip shield or contact the drip shield below the locations of any breaches. Consequently, assuming all seepage occurs at the crown of the drift results in an upper bound to the flux that could be transmitted through any breaches in the drip shield to the waste package.

2.1.4 Summary of Approach to the Issues in the Seepage Model

The following summarizes the approach to accounting for the effects of film flow and small-scale tunnel irregularities in the seepage model:

- The impact of film flow on seepage is appropriately accounted for through the estimation of an effective model parameter that is determined by calibration against seepage data obtained through water release experiments, which by their nature incorporate the seepage processes, including film flow, along the drift wall.
- Small-scale irregularities are implicitly accounted for through (1) explicit discretization of the opening, (2) neglect of flow diversion in a 0.05-m-thick layer around the drift (mimicking small-scale surface roughness with a 0.05-m amplitude of the irregularities), and (3) estimation of an effective capillary-strength parameter.
- The combined effects of film flow and small-scale drift wall irregularities are taken into account in a bounding approach in the EBS flow abstraction.

2.2 IMPORTANCE OF THE ISSUES TO THE CAPABILITY OF THE BARRIERS IMPORTANT TO WASTE ISOLATION

2.2.1 Roles of the Barriers in Waste Isolation

The issues that underlie these KTI Agreements pertain to the capability of the barriers to limit the movement of water and the mobilization and movement of radionuclides. The importance of these issues depends upon the roles of the barriers in the assessment of total system performance. These roles are described in *Risk Information to Support Prioritization of Performance Assessment Model* (BSC 2002, Section 2.1). The following discussion summarizes these roles.

Nominally Expected Conditions–Natural barriers of the system limit the movement of water that could contact waste and transport radionuclides away from the repository. These barriers include the surficial soils and topography that limit infiltration into Yucca Mountain and also include the unsaturated zone above the repository horizon that limits percolation down to the repository horizon and seepage of water into the emplacement drifts. These barriers directly affect performance of the repository in two ways. First, they constrain the environments under which the engineered barriers would function. Because these environments are stable (change very slowly), it is possible to design engineered barriers whose characteristics are predictable. Second, they limit the exposure of waste to water. Because of the limited amount of water present, a large portion of the repository would remain dry. Even in the wetted portion of the repository, the fluxes of water are small and only a limited fraction of the radionuclides can be mobilized after a waste package is breached.

Natural barriers also limit the movement of radionuclides away from the repository to the accessible environment. These barriers include the unsaturated zone below the repository horizon and the saturated zone flow and transport barrier. These barriers limit movement of radionuclides because the movement of water that carries them through the rock is, on average, very slow. In addition, processes in the rock retard the movement of the radionuclides relative to

the water movement in the rock. These barriers are sufficiently effective that only a small fraction of the radionuclides that reaches these barriers could reach the accessible environment in less than 10,000 years.

Under the nominal scenario class, the amount of radionuclides reaching the accessible environment is also limited by the engineered barriers. If the waste packages remain intact, no radionuclides are released in 10,000 years. Even if some of the waste packages are breached before 10,000 years, intact drip shields over the waste packages prevent exposure of waste to moving water. As a result, release of radionuclides from breached waste packages to the natural barriers can only occur by diffusion through the drift invert. It is difficult for most of the radionuclides to diffuse through the breached waste package and drift invert because of solubility limits, low diffusion gradients and sorption. As a result, only highly soluble and mobile radionuclides (i.e., radionuclides such as technetium-99 and iodine-129) are able to reach the natural barriers in 10,000 years in non-negligible quantities. The potential mean annual dose to the reasonably maximally exposed individual from these radionuclides is small.

If, in addition to breached waste packages, the drip shields over these waste packages are degraded sufficiently to permit flowing water to contact the waste in the waste packages, the amount of radionuclides that can be mobilized and released to the natural barriers can be larger. This amount is limited by the solubility of dissolved radionuclides and the concentration of colloid-associated radionuclides that can be suspended in the water contacting the waste form.

For commercial spent nuclear fuel, the amount of radionuclides that can be released from the engineered barriers to the natural barriers is also limited by fuel cladding. As long as the cladding remains intact, the uranium oxide is not exposed to the water, and the radionuclides cannot be mobilized.

Therefore, under expected conditions, the system is able to isolate waste primarily because

- The set of waste packages remains substantially intact and limits the amount of radionuclides that can be mobilized to a small fraction of the total inventory.

- Independent of waste package performance, the set of drip shields remains substantially intact and limits the release of radionuclides to diffusive release through the drift invert, resulting in only a small fraction of the mobilized radionuclides reaching the natural barriers annually.

- The radionuclide solubility limits and the waste form degradation rates, including the cladding of commercial spent nuclear fuel, constrain the rate of mobilization of radionuclides in any waste packages that might be breached.

- The unsaturated zone below the repository barrier and the saturated zone barrier each independently limit the amount of radionuclides that can reach the accessible environment in 10,000 years to a small fraction of the amount of radionuclides reaching these barriers annually.

Disruptive Conditions–Disruptive conditions are those conditions that result from low-probability events that potentially damage barriers of the repository system. The role of the set of repository barriers is somewhat different under disruptive conditions in which some waste packages, drip shields, and commercial spent nuclear fuel cladding are damaged (BSC 2002, Section 2.1.2). For example, under igneous intrusion, intruding magma damages some of the engineered barriers, exposing waste to water moving down through the unsaturated zone. In this case, the affected part of the repository does not benefit from containment by the waste packages or diversion of water by the drip shields. As a result, the radionuclides that can be released from the repository are not restricted to mobile radionuclides, but may include less-mobile radionuclides such as plutonium-240 and 241 and neptunium-237 that can be transported advectively by moving water.

The potential mean annual dose from these radionuclides could be large. However, impacts on risk from release of these radionuclides are limited by three factors. First, the risk in this case is limited by the low probability that the disruptive conditions occur. Second, in the event the repository is disrupted, the total amount of water contacting the waste cannot be greater than the maximum amount of precipitation that might fall onto Yucca Mountain over that period. The TSPA model includes a range of uncertainty in the estimate of seepage into the emplacement drift, yet estimates of mean annual dose are orders of magnitude below the regulatory standard. Sensitivity studies with higher seepage (e.g., Section 2.3 of this report) have similar results. Consequently, the effects of increased seepage are unlikely to result in a significant impact on the risk estimates. Third, the 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.

2.2.2 Effects of Seepage Issues on the Capability of the Barriers Important to Waste Isolation

The issues underlying these KTI agreements are relevant to the extent they could change the picture of waste isolation provided in Section 2.2.1. In particular, the possibility of higher seepage than expected could affect the capability and roles of some of the barriers of the repository system that are expected to limit movement of water and radionuclides. Potential effects of increased seepage on the capability and roles of these barriers are:

- If the surface barrier and unsaturated zone flow barrier above the repository were less effective than expected, seepage into the emplacement drift could be higher than represented in the model. Increased seepage would have little effect on the waste package diffusive release because of the diversion of the seepage by the drip shields. Increased seepage could affect waste package advective release. However, the uncertainties in this case are of the same nature as those associated with film flow or small-scale tunnel irregularities: they are uncertainties in the amount of seepage that might contact the waste package and the waste. They do not therefore introduce conceptually different concerns than are addressed in this letter report.

- Increased seepage could result in an increased fraction of titanium drip shields that would be in an aqueous (rather than humid air) environment. Likewise, increased seepage also means that a larger fraction of the Alloy 22 waste packages (in the event of

drip shield failure) could be in an aqueous (rather than humid air) environment. However, measurements show that general corrosion rates for titanium and Alloy 22 are similar in aqueous and humid air environments, implying that higher seepage would not decrease drip shield and waste package lifetimes (CRWMS M&O 2000a, Section 6.2 and 6.3, and CRWMS M&O 2000b, Section 6.9).

- Increased seepage could change the chemistry of aqueous films on the drip shields and waste packages. However, the drip shield and waste package degradation models are calibrated to tests conducted over a range of environments, which were developed to bound in-drift chemical environments (CRWMS M&O 2000a, Section 1.8, and CRWMS M&O 2000b, Section 1.9). Thus, increased seepage is not expected to decrease system capabilities in this regard because none of the drip shields are calculated to fail before 10,000 years for the base case and the enhanced drip shield degradation rate case (BSC 2002, Section 3.3.4 and Figure 10).

- Other corrosion modes, such as localized corrosion and stress corrosion cracking, are not sensitive to increased amounts of water that may arise from higher seepage. With regard to effects of changes in chemistry, current data regarding Alloy 22 and titanium indicate that conditions required for localized corrosion would not be reached under the expected repository conditions (CRWMS M&O 2000c, Sections 5.3 and 5.4).

- Increased seepage could affect the rate of degradation of the waste forms. However, these degradation rates have been evaluated and found not to play an important role in the estimates of releases from the repository system largely because the degradation rates are so high (BSC 2002, Section 3.3.6). Consequently, degradation rates that might be associated with increased seepage are not expected to be significantly higher or to significantly affect overall performance.

- Increased seepage would not be expected to affect performance of commercial spent nuclear fuel cladding unless the seepage water increases the fluoride available for localized corrosion (CRWMS M&O 2001b, Sections 6.2 and 6.3). Sensitivity studies show that the effect of any increase in localized corrosion that might be associated with fluoride would not be significant to risk (BSC 2002, Section 3.3.6 and Figure 19).

- Increased seepage could affect the chemistry of the water contacting the waste, which could, in turn, change the concentrations of dissolved or colloid-associated radionuclides in that water. However, the in-package chemistry model already takes into account interactions of water with the waste form and other internal components of the waste package (BSC 2001c, Section 1). The effect of increased seepage would be to increase dilution and possibly lower temperatures and would not result in increased concentrations beyond those already estimated.

- Increased seepage could increase wetting of the drift invert and affect diffusive transport there because the invert diffusivity is a function of the invert moisture content. However, the estimates of mean annual dose do not show a significant sensitivity to the moisture content of the drift invert (BSC 2002, Section 3.3.9). Accordingly, uncertainty

in seepage does not have significant implications for the role of the drift invert in waste isolation.

- Increased seepage could in principle affect moisture conditions in unsaturated rock directly below the emplacement drifts and affect radionuclide transport in this zone. However, estimates of mean annual dose do not show significant sensitivity to flow conditions in the unsaturated zone below the repository (BSC 2002, Section 3.3.1).
- Increased seepage is not likely to have any direct effect on the capabilities of the saturated zone flow and transport barrier because it is unlikely to change saturated zone flow and transport properties.

2.3 IMPORTANCE OF THE ISSUES TO MEAN ANNUAL DOSE

The discussion in Section 2.2, and its subsections, of the effects of the issues associated with these KTI agreements on barrier capabilities suggests that these issues are not likely to have a significant effect on overall repository system performance. A TSPA analysis has been conducted to determine if this suggestion is confirmed for the estimates of mean annual dose.

Figure 1 shows the base case for this analysis. The results in this figure are base-case results from *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Section 3.1). Appendix A provides information on the details of this model. The radionuclides that dominate the estimate of mean annual dose for the nominal scenario class in this TSPA analysis are carbon-14, technetium-99, and iodine-129. These radionuclides are highly soluble (CRWMS M&O 2000d, Table 3.5-8) and their mobilization is controlled by waste form degradation rates. In addition, these radionuclides tend to be mobile because they move as neutral or anionic species and are not strongly sorbed. The mean annual dose estimates for this scenario class are more than five orders of magnitude below the regulatory standard of 15 mrem. The radionuclides that dominate the estimate of the probability-weighted mean annual dose for the igneous intrusion modeling case include neptunium-237, plutonium-239, and plutonium-240. These radionuclides are less soluble than are those that dominate the estimate for the nominal scenario class, and their mobilization is controlled by their solubility. The mean annual dose estimate for this case is more than three orders of magnitude below the regulatory standard.

A TSPA sensitivity study has been conducted to quantitatively assess the effects of potentially higher seepage within the emplacement drift (BSC 2002, Section 3.1). A summary of the changes to the base-case model for the sensitivity study is provided in Appendix A to this letter report.

Figures 2 and 3 compare the mean and 95th percentile results of the base-case model with results obtained using a higher seepage flux. The base-case model results in zero seepage over approximately half of the waste packages (BSC 2001a, Section 4.2.2) with a bounding value for seepage flux of 1 m^3/yr within the regulatory period (BSC 2001a, Figures 4.2.2-1 and 4.2.2-3). The sensitivity study model considers the effect of seepage of 1 m^3/yr over the location of every waste package, an average of nearly a factor of 20 greater than the average flux of the base-case model. The sensitivity study also uses the flow field that results from the maximum infiltration rate associated with the glacial maximum climate. Because this is the maximum infiltration rate

modeled, the resulting flow field is the most conservative case available for the sensitivity study. The base case and sensitivity study models, therefore, encompass a range of fluxes that permits insight into the potential effect of uncertainties in the base-case representation of seepage, including the effects of the uncertainties associated with the potential for film flow and small-scale tunnel irregularities.

The mean annual dose results for the nominal scenario class show no significant difference in the first 10,000 years (Figure 2). Two factors determine the small effect. The first is that the drip shield remains intact in this scenario class; therefore, increases in the seepage flux do not directly lead to increased flux through breached waste packages. Consequently only diffusive release from these waste packages can occur. Secondly, the carbon-14, technetium-99, and iodine-129 that dominate diffusive release are soluble, and their release is not significantly affected by the amount of water that may be present.

The effect of increased seepage on mean annual dose is somewhat higher for the igneous intrusion modeling case between the base case and sensitivity study results (Figure 2). Because drip shields are damaged in this modeling case, advective flow through the waste package is possible. In this case, the dominant radionuclides (neptunium-237, plutonium-239, and plutonium-240) are solubility-limited, and the estimate of mean annual dose increases essentially in proportion to the increase in seepage. However, this increase amounts to less than 0.02 mrem, which is insignificant in comparison with the regulatory standard of 15 mrem.

Figure 3 illustrates the effects of base-case uncertainties in other TSPA model components in combination with the higher seepage rate. This figure shows the 95th percentile dose estimates obtained by sampling over the uncertainties. The focus of the sensitivity study, the seepage flux, is fixed at the high value and is not sampled; however, all other parameters are sampled over their ranges of uncertainty. In both the nominal scenario class and the igneous intrusion modeling case, the 95th percentile results remain below 15 mrem. Therefore, uncertainties in the seepage model, even considered in combination with other uncertainties, are not likely to result in significant impacts on the assessment of repository performance. This result is consistent with the barrier capability discussion in Section 2.2. Accordingly, effects of film flow or small-scale asperities that could affect the estimate of seepage are not expected to play an important role in determining compliance with the individual and groundwater protection requirements.

2.4 COMBINED EFFECTS

The one-off sensitivity studies may not fully address the importance of uncertainties in the seepage model. Uncertainty importance analyses consistently show that the uncertainties that dominate the variance in the estimates of total system performance are those related to waste package performance. For example, analyses for the Site Recommendation show that the largest contributors to the uncertainty in the estimate of mean annual dose for the nominal scenario are those related to degradation of the waste package outer barrier and lid (CRWMS M&O 2000d, Figure 5.1-4). Consequently, effects of uncertainties in the seepage model, such as those that underlie these agreements, may be masked by waste package performance and may not be apparent in sensitivity studies for the nominal scenario class. To an extent, this problem is reduced in the sensitivity studies for the igneous intrusion modeling case where masking by the waste packages and drip shields is removed. A second issue is that the uncertainties in the

seepage model may combine with uncertainties in other TSPA model components. The full importance of these uncertainties may therefore not be fully addressed in one-off sensitivity studies. An effort to address both of these problems has been made by studying the effects of large changes in the seepage model in combination with changes in other TSPA model components, including those associated with the waste package.

The Combined Effects Sensitivity Study in *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Section 3.4) explicitly reports the results of considering combined effects of large changes to the probability models for several TSPA model components. These suites of model components do not all have the same importance relative to the estimation of mean annual dose. Risk sensitive studies, such as seepage analysis presented here, have been used by DOE to address some KTI issues. However, this combined effects analysis includes changes to models (e.g., waste package degradation) that will not be included in sensitivity analysis used to address KTI agreements. In addition to the seepage model, the study evaluates the importance of simultaneous changes to the probability models for the following TSPA model components:

- Mean infiltration rate
- In-drift chemistry
- Drip shield degradation
- Waste package degradation
- In-package chemistry
- CSNF cladding performance
- Dissolved radionuclide concentration limits
- Colloid-associated radionuclide concentrations
- Unsaturated zone radionuclide transport

The change in the seepage model for the combined effects sensitivity studies is the same as that considered in the sensitivity studies of Section 2.3. That is, the seepage is changed from an average of less than 0.1 m^3/yr over approximately half the waste packages to 1 m^3/yr over every waste package. The implementation of this change is described in Appendix A.

The changes made to the other TSPA component models for the combined effects sensitivity studies are the following:

1. **Climate, net infiltration, and unsaturated zone flow**—The flow field associated with the highest infiltration rate, about 150 mm/yr for the glacial maximum climate, is used for the entire time period of the analysis (BSC 2001a, Figure 4.2.2-1).

2. **In-drift chemistry**—The pH for the supplemental TSPA model ranges from between 4.8 to 7.3 in the first 4,000 years and from 7 to 8 thereafter (BSC 2001a, Figure 4.2.4-1). This is changed to a pH of 4, which is a bounding value outside the pH range used in the supplemental model (BSC 2001a, Figure 4.2.4-1).

3. **Drip shield degradation**—In the supplemental TSPA model the median drip shield corrosion rate is 0.025 microns/yr and the 95th percentile is 0.12 microns/yr (CRWMS M&O 2000b, Section 6.5.4). The measured corrosion rate is corrected for deposition of silicates

during experimentation by adding a factor that ranges from 0 to 0.063 microns/yr. The approach for this analysis is to utilize the 95th percentile of the uncorrected measurements and to increase it by 0.17 microns/yr to ensure the analysis goes beyond the range of the correction factor. The effective general corrosion rate is 0.29 microns/yr, more than 2.5 times the 95th percentile value.

4. **Waste Package General Corrosion**—The mean general corrosion rate for the waste package is 0.01 microns/yr and the 95th percentile is 0.04 microns/yr (CRWMS M&O 2000b, Section 6.9.1). For the waste package, the general corrosion rate is changed to a value that is eight times greater than the base-case corrosion rate. The combined effects sensitivity study general corrosion rate is a distribution with the same shape as the base-case distribution. The distribution is based on the 24-month weight loss measurements, the uncertainty range for the silicate deposition correction, and the range for enhancements due to thermal aging and microbial effects. The entire distribution for the base case is increased by a factor of 8 in the combined effects sensitivity study. This increase is based on a higher weight loss range (calculated based on 6- and 12-month weight loss measurements which have a greater uncertainty), the upper conservative bound of the silicate deposition correction, and the maximum enhancement factors for the aging and microbial effects. This higher general corrosion rate distribution is beyond the uncertainty range in the TSPA model.

5. **In-package chemistry**—The base-case pH values for the nominal scenario range between 3.4 and 7.7 (BSC 2001d, Tables 9-3, 9-4, and 9-5). The combined effects sensitivity study used a pH of 4, the same value as used for the in-drift chemistry model. This value also provides a reasonable bound for the in-package pH and does not result in any precipitation effects due to changing chemistry for concentration that move from the waste package to the drift invert.

6. **CSNF cladding performance**—Early cladding failures range from about 8 percent for TSPA-SR to 1 percent for the supplemental TSPA analysis (CRWMS M&O 2000d, Section 5.3.4.1; BSC 2001a, Section 3.2.7.2). For the combined effects sensitivity study the early failure rate is changed to an assumption that all cladding is breached at the time of emplacement. This is a bounding approach for the cladding of the combined effects sensitivity study.

7. **Dissolved radionuclide concentration limits**—The dissolved radionuclide concentrations component of the TSPA model determines the solubility limits for radionuclides as a function of temperature and chemistry of the water (CRWMS M&O 2000d, Section 3.5.5). These limits are therefore changed because of the changes to the in-package and in-drift chemistry assumed for this study. In addition to this change, the concentration limits are further increased by a factor of 10.

8. **Colloid-associated radionuclide concentrations**—The nominal concentration of colloids associated with plutonium and americium used in the supplemental TSPA model (CRWMS M&O 2000a, Section 3.5.6) was increased to a value of 1.5 above the maximum allowed in the base case.

9. **Unsaturated zone radionuclide transport**—In the base-case model, radionuclide flux from the engineered barrier system is distributed between the fast-travel-path fractures and the slow-travel-path matrix of the unsaturated zone rock. In the nominal scenario, almost all of the radionuclides go into the slow-travel-path matrix. For the combined effects analyses, all of the radionuclide flux from the engineered barrier system is transmitted into the fast-travel-path fractures. This approach is a reasonable lower bound to the radionuclide travel times through the unsaturated zone.

Figure 4 shows the increase in mean annual dose associated with these extreme changes ranges from two to three orders of magnitude in the first 10,000 years. While this represents a large relative change, it does not represent a significant change in terms of the regulatory standard. For example, for the igneous intrusion modeling case, the peak mean annual dose in 10,000 years increases to about 0.9 mrem. This increase is due to the significant increase in solubility of plutonium and much higher seepage rates. However, even for these extreme changes, the regulatory standard is not exceeded. For the nominal scenario class, the peak mean annual dose in 10,000 years is increased to 0.1 mrem, more than a factor of 100 below the regulatory standard. The change in this case is due to the higher solubility of plutonium and to the increased exposure of CSNF fuel due to the neglect of CSNF cladding. These results indicate that if all of these changes were to be realized mean annual dose would still be more than a factor of 10 below the individual protection standard.

These changes represent reasonable bounds to the respective TSPA model components or, in some cases, parameter values that are well outside the range of uncertainty for them. The probability of any single change is very low and the combined probability of all of them at once is not sufficiently credible to warrant consideration. However, even ignoring the reduction in the estimate of risk that would occur if the individual probabilities of these changes were taken into account, the estimate of mean annual dose remains below the regulatory standard. These results suggest strongly that uncertainties in the seepage model are not likely to combine with uncertainties in other TSPA model components to result in an estimate approaching the regulatory standard.

3. CONCLUSION

The technical basis for the treatment of film flow at low seepage fluxes and of small-scale tunnel irregularities associated with drift collapse, and their propagation into the TSPA model will be commensurate with their risk significance, i.e., their effects on total system performance. That risk significance includes the importance of the unsaturated zone flow barrier above the repository, and other barriers that might be affected by increased seepage, in meeting the individual and groundwater protection requirements of 10 CFR 63.113 and in describing the capabilities of the barriers important to waste isolation.

The current information indicates that the understanding of the distribution of water in the emplacement drifts is adequate without precise prediction of the seepage, including potential increases that might occur due to the effects of film flow or small-scale tunnel irregularities. The TSPA sensitivity study results presented in Section 2.3 indicate that these effects do not play a significant role in determining whether the individual protection requirement would be met. Similar conclusions would be drawn with respect to the determination regarding the groundwater

protection requirement (BSC 2002, Section 2.2). Therefore, the current representation and its technical basis are adequate for compliance with the associated regulatory requirements for individual and groundwater protection. The technical basis discussed in Section 2.1, the physical arguments provided in Section 2.2, and the supporting TSPA sensitivity studies in Section 2.3 and 2.4 are provided to address agreements USFIC 4.02 and 4.03.

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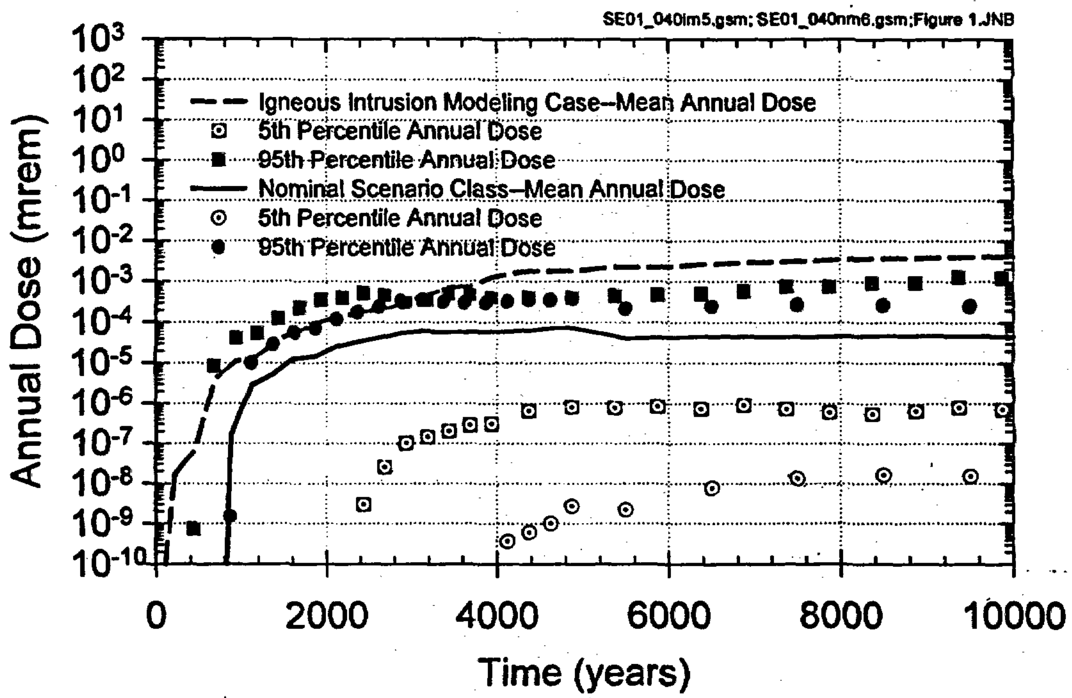
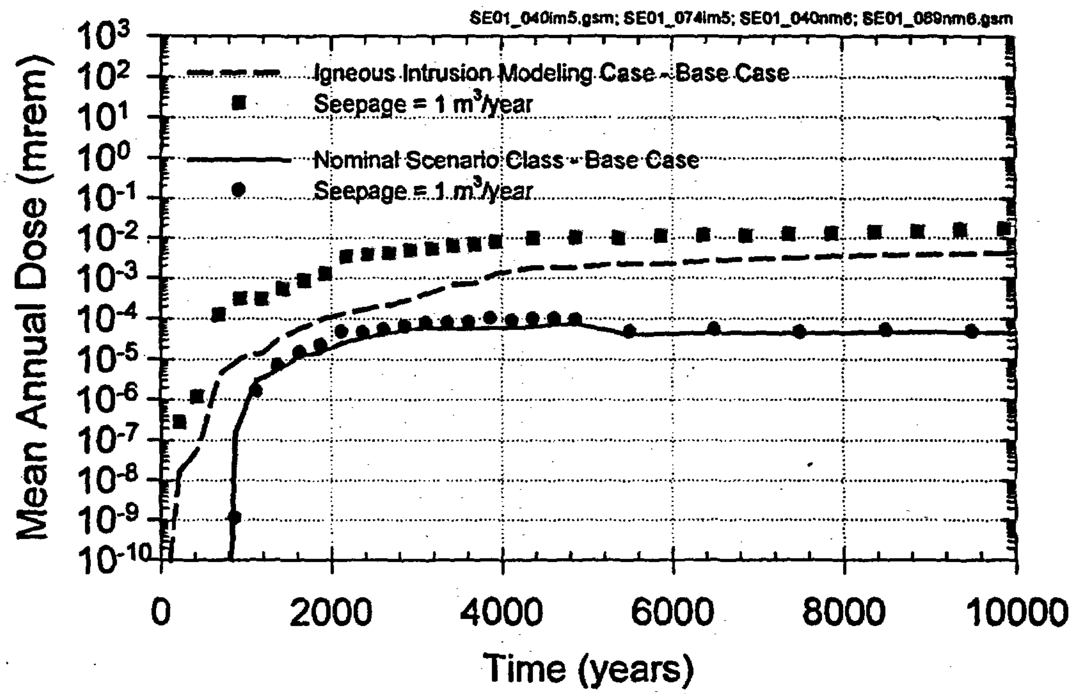


Source: The results in this figure are adapted from the data file supporting *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Figure 1).

NOTES: 1) Each mean annual dose curve is a probability-weighted average.

2) The 95th percentile curve for igneous intrusion is below the mean after 3000 years because the mean is dominated by one of the 300 realizations after that time. That realization has a peak risk (probability weighted annual dose) of about 1.1 mrem at 10,000 years

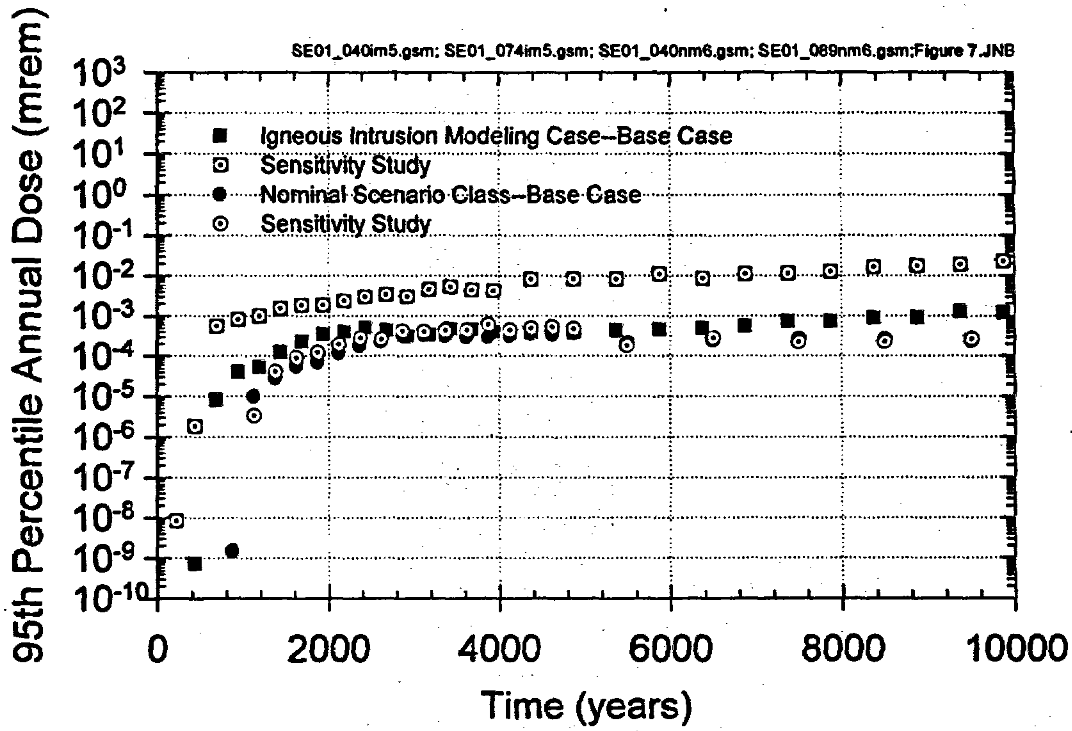
Figure 1. Estimate of Annual Dose for the Nominal Scenario Class and Igneous Intrusion Modeling Case



Source: The results in this figure are adapted from *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Figure 7).

NOTE: Each mean annual dose curve is a probability-weighted average.

Figure 2. Sensitivity of Mean Annual Dose to Seepage into Emplacement Drifts

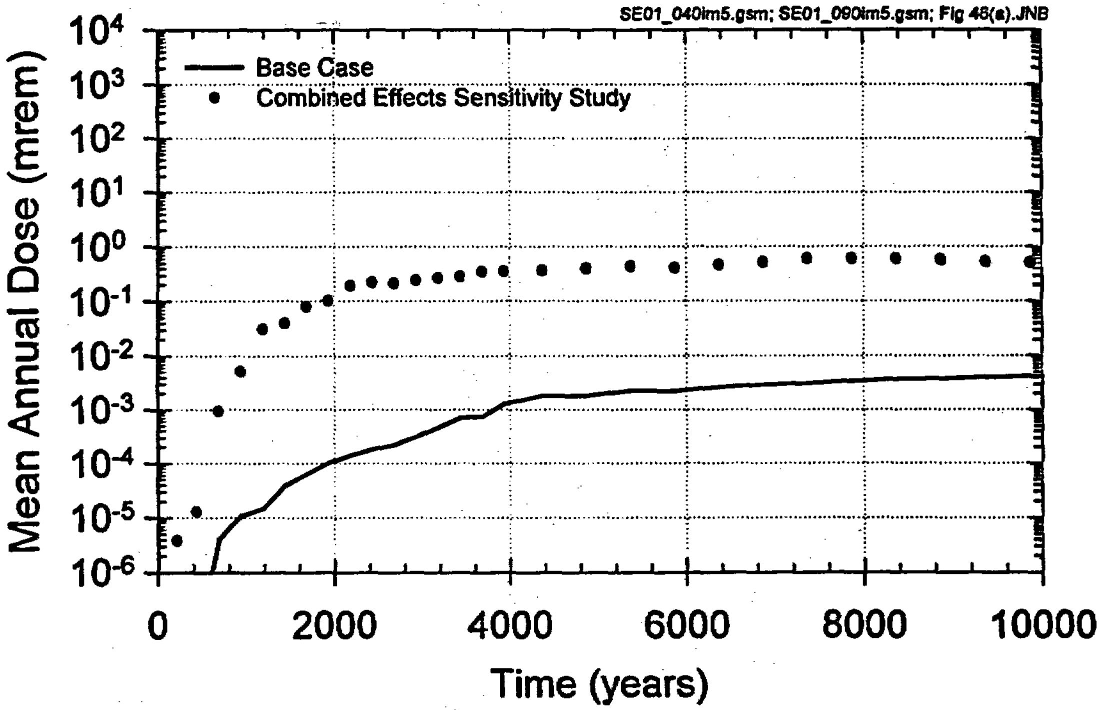


Source: The results in this figure are adapted from the data file supporting *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Figure 7).

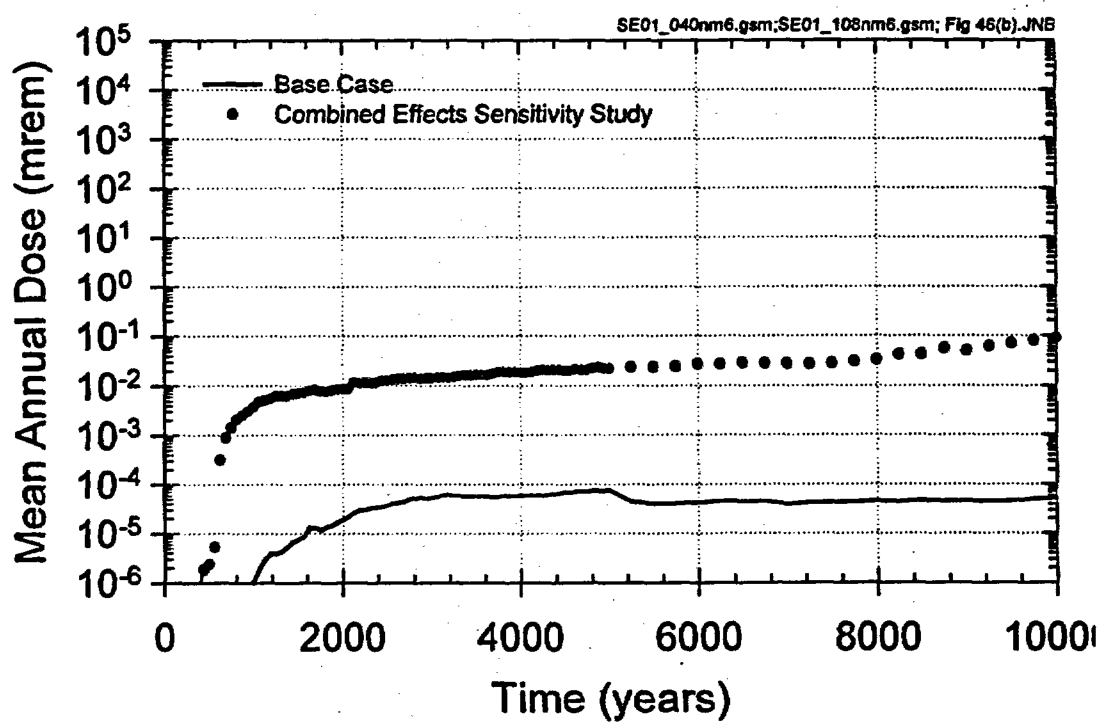
NOTE: Each annual dose curve is a probability-weighted average.

Figure 3. 95th Percentile of Annual Dose Estimates for the Seepage Sensitivity Study

(a) Igneous Intrusion Modeling Case



(b) Nominal Scenario Class



Source: The results in this figure are adapted from the data file supporting *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Figure 46).

NOTE: Each annual dose curve is a probability-weighted average.

Figure 4. Effect of Combinations of Variations in TSPA Model Components.

APPENDIX A: SUMMARY OF CHANGES TO THE TSPA MODEL FOR SEEPAGE MODEL SENSITIVITY STUDIES

Base Cases

- Igneous Modeling Case = SE01_040im5
- Nominal Scenario Class = SE01_040nm6

The TSPA model for the base case is similar to the revised supplemental model used for the Site Suitability Evaluation and the Final Environmental Impact Statement (Williams 2001).

The base-case TSPA models for these studies differs from the revised supplemental model in only three ways. These changes were made to improve calculational efficiency for the large number of cases evaluated. The first difference is that the number of realizations used in the Monte Carlo sampling for the igneous scenario is reduced; that is, the base-case model for this scenario is the same as the revised supplemental model except that a smaller number of realizations is calculated. The revised supplemental analyses calculated 5,000 realizations for the igneous activity scenarios while the studies reported in this document calculate only 300 realizations. Figure 2 in *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002) compares the results using 5,000 realizations with those using only 300 realizations. The difference between these two cases is not significant. Consequently, utilization of only 300 realizations for this scenario appears to be adequate for assessing the relative role of the TSPA model components in this case.

The second difference between the base-case model for these sensitivity studies and the revised supplemental model is in the approach to the igneous activity groundwater release scenario. The approach to specifying the time of occurrence of the igneous intrusion is to sample over the calculational period (100,000 years). The approach for the revised supplemental analyses is to sample uniformly over this period. The total number of realizations is therefore divided up among the time steps, and only about 10 percent of the realizations are associated with the events occurring in the first 10,000 years. Of these, only the events at the end of the 10,000 years receive the full benefit of that fraction of realizations, and events occurring earlier benefit from a proportionally fewer realizations. In order to provide accurate representation of events occurring in the early period, a large number of realizations is necessary to ensure that the number of realizations in which the event occurs in the early period is large enough.

One way to deal with this problem is to increase the number of realizations occurring in the early period without increasing the total number, e.g., by weighting the sampling toward the early period. Figure 3 of *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002) compares the result of the revised supplemental model linear sampling scheme (circles) with the result of a scheme in which the sampling is logarithmic with time (triangles). This approach to the sampling increases the estimate of mean annual dose in the early period because more contributions from the tails of the probability distributions (which could result in increased release of radionuclides) are captured. These additional contributions increase the estimate of mean annual dose over that from the linear sampling scheme.

The weighted sampling scheme approach still requires a large number of realizations to ensure a stable mean in the early period. Another way to deal with this problem is to assume that the

variation in processes affecting release does not depend strongly on the time the event occurs. In this case, the same release curve can be used to represent system performance whenever the igneous intrusion event occurs. All realizations are then devoted to this single curve. The effect is to increase the ability to capture the full range of each probability distribution with a smaller number of realizations. Figure 3 of *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002) shows the result of this approach using only 300 realizations (solid curve). The result is comparable to that for the logarithmic sampling approach. Some effects are not accurately accounted for in this approach (e.g., glacial maximum climate that occurs at a fixed absolute time and not simply at some time after the event occurs). However, the glacial maximum climate occurs at 39,000 years, so that the approach appears to be reasonable for estimating the effects in the first 10,000 years.

The third difference between the base-case model for these sensitivity studies and the revised supplemental model is in the treatment of early waste package failure due to improper heat treatment in the nominal scenario. Such early failure has very low probability; consequently, only a fraction of the realizations in a TSPA study will contain such a failure. The effect for the revised supplemental model is that out of 300 realizations, fewer than 70 will involve any early waste package failure. This number of realizations is not sufficient to provide a reliable estimate of effects that come into play only when the early failure occurs. The approach used here is to force early failure of one package in every realization, increasing the number of realizations for the models and parameters that come into play when a waste package is breached. This approach results in a higher mean annual dose associated with these early failures. Figure 4 of *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002) compares the results from this base-case model with those from the revised supplementary model. The nominal scenario result for the revised supplementary model is a fraction (0.26) of the nominal scenario result for the base-case model. This difference is not likely to be significant in assessing the role of various TSPA model components in the estimate of mean annual dose. Consequently, the advantage of providing a more stable estimate of the mean annual dose without increasing the number of realizations is considered to outweigh the disadvantage of the overestimate of the mean annual dose in the early period.

These three changes were adopted to expedite the sensitivity studies. They are not likely to affect conclusions regarding the relative importance of the different model components.

The results of the base cases and all sensitivity studies were submitted to the Technical Data Management System as documented in the *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002).

Sensitivity Cases:

- SE01_074im5 for Igneous Intrusion Seepage Sensitivity Modeling Case
- Scenario Class SE01_089nm6 for Nominal Scenario Class

The objective of these cases is to use the worst-case flow through the unsaturated zone in conjunction with a constant 1-m^3/yr seepage flux throughout the repository. All sensitivity studies utilizing the base-case model are fully probabilistic, employing a Monte Carlo sampling approach.

To provide the worst-case flow field, three FEHM files must be defined: the flow field file, the particle tracking file, and the Zone 2 file. The worst-case flow field available for the sensitivity study is the ff5000.ini, which corresponds to the highest flow glacial climate state. The FEHM code is forced to always use this file by (1) setting the Flowfield_Index column variable to always be equal to 3, (2) deleting the original ff0300.ini file and replacing it with a copy of the ff5000.ini file, and (3) changing the values in rows 2 through 6 in column 3 of the Flowfield_Index table to be equal to 5000. The worst-case particle tracking and Zone 2 files are those for high infiltration: ptrk.multrlz.0300 and fm_pchm1.zone2.0300 respectively. By setting the Flowfield_Index column variable to always be equal to 3, these latter two files are always used by FEHM.

To set the seepage flux to a constant 1 m^3/yr, the SeepFlux_Al_CSNF_x_multi and SeepFlux_Al_CDSP_x_multi data elements (where x = 1 to 5) are set to define the data locally, and the local data table is set to 1 m^3/yr. The fraction of drifts that experience seepage is set to 100% percent (SeepFrac_Al_x_multi, values fixed to 1).

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APPENDIX B: SUMMARY OF CHANGES TO THE TSPA MODEL COMBINED EFFECTS SENSITIVITY STUDIES

Base Cases

Igneous Modeling Case = SE01_040im5
Nominal Scenario Class = SE01_040nm6

The TSPA model for the base case is similar to the revised supplemental model used for the Site Suitability Evaluation and the Final Environmental Impact Statement (Williams 2001). These cases are described in Appendix A.

Sensitivity Cases:

Igneous Intrusion Modeling Case Combined Effects Sensitivity Study = SE01_090im5
Nominal Scenario Class Combined Effects Sensitivity Study = SE01_108nm6

The objective of these cases is to use reasonable bounds for a number of TSPA model components in a single combined effects study for the igneous activity modeling case and the nominal scenario class. The following changes were made to the base-case TSPA model.

Reasonable bound to the unsaturated zone flow field

To provide a reasonable-bound flow field, three FEHM files are defined: the flow field file, the particle tracking file, and the Zone 2 file. A reasonable-bound flow field available for the sensitivity study is the ff5000.ini, which corresponds to the highest flow glacial climate state. The FEHM code is forced to always use this file by (1) setting the Flowfield_Index column variable to always be equal to 3, (2) deleting the original ff0300.ini file and replacing it with a copy of the ff5000.ini file, and (3) changing the values in rows 2 through 6 in column 3 of the Flowfield_Index table to be equal to 5000. The worst-case particle tracking and Zone 2 files are those for high infiltration: ptrk.multrlz.0300 and fm_pchm1.zone2.0300 respectively. By setting the Flowfield_Index column variable to always be equal to 3, these latter two files are always used by FEHM.

Reasonable bound to seepage

To set the seepage flux to a constant 1 m^3/yr, the SeepFlux_Al_CSNF_x_multi and SeepFlux_Al_CDSP_x_multi data elements (where x = 1 to 5)are set to define the data locally, and the local data table is set to 1 m^3/yr. The fraction of drifts that experience seepage is set to 100% percent (SeepFrac_Al_x_multi, values fixed to 1).

Reasonable bound to in-drift chemistry

Set pH_Invert to 4.

Reasonable bound to in-package chemistry

Set pH_CDSP, pH_CSNF, and pH_Crown to 4.

Reasonable bounds to dissolved radionuclide concentrations

For Water and Invert_Water, set solubilities of dissolved radionuclides to 10 times their base-case solubilities.

Reasonable bounds to colloid-associated radionuclide concentrations

- Set M_Col_Wf_Both_WP_Irrev to M_Col_Wf_Both_Max times CPu_Col_Wf_Irrev_a divided by CPu_Col_Wf_Irrev_Max (multiplied by 1.5).
- Set M_Col_Wf_Both_WP_Rev to M_Col_Wf_Both_Max times CPu_Col_Wf_Irrev_b divided by CPu_Col_Wf_Irrev_Max (multiplied by 1.5).
- Set CPu_Col_Wf_Irrev_a and CPu_Col_Wf_Irrev_b to 1.5 times their maximum values.
- Set M_Col_Wf_Both_Invert to M_Col_Wf_Both_Max times CPu_Col_Wf_Irrev_Invert divided by CPu_Col_Wf_Irrev_Max (multiplied by 1.5).
- Set CPu_Col_Wf_Irrev_Invert to M_Col_Wf_Both_Max times CPu_Col_Wf_Irrev_Invert divided by CPu_Col_Wf_Irrev_Max (multiplied by 1.5).
- Set CPu_Col_Wf_Irrev_Invert to 1.5 times the maximum value in the Invert.
- Set CPu_Col_Wf_Irrev_Invert_b to 1.5 times the maximum value in the Invert.

Reasonable bound to CSNF cladding perforation

Set Clad_Fraction_Perforated to 1.

Reasonable bound to waste package degradation rate

Set Lines 996 and 1019 of WAPDEG input equal to 8 and Lines 997 and 1020 to 16.

Reasonable bound to drip shield degradation rate

Define data element UU_DS, the parameter that selects the percentile of the corrosion rate on DS, to 0.95. Set WDgTi7SR00 and WDnTi7SR00 equal to UU_DS.