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QA: N/A

JAN 21 2003

OVERNIGHT MAIL

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TRANSMITTAL OF REPORT ADDRESSING KEY TECHNICAL ISSUE (KTI) AGREEMENT ITEMS TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI) 3.18, 3.21, AND 3.23 AND THERMAL EFFECTS ON FLOW (TEF) 2.13

This letter transmits a report entitled *Response to TSPAI 3.18, 3 21, 3.23, and TEF 2 13,* which provides the basis for closure of the subject KTI agreement items. The agreements read as follows:

> <u>TSPAI 3.18</u>: "Provide a technical basis that the water-balance plug-flow model adequately represents the non-linear flow processes represented by Richard's equation, particularly over the repository where there is thin soil (UZ1.2.1).
> DOE will provide a technical basis that the water-balance plug-flow model adequately represents the non-linear flow processes represented by Richard's equation, particularly over the repository where there is thin soil. The technical basis will be documented in an update to the Simulation of Net Infiltration for Modern and Potential Future Climates AMR (ANL-NBS-HS-000032). The AMR is expected to be available to NRC in FY 2003."

> <u>TSPAI 3 21</u>: "Demonstrate that effects of near surface lateral flow on the spatial variability of net infiltration are appropriately considered (UZ1.5.1).
> DOE will demonstrate that effects of near surface lateral flow on the spatial variability of net infiltration are appropriately considered in an update to the Simulation of Net Infiltration for Modern and Potential Future Climates AMR (ANL-NBS-HS-000032) and UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006). These AMRs are expected to be available to NRC in FY 2003 "

NMSSO1

TPSAI 3.23: "DOE should evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts and transport. DOE should also provide a technical basis for the assessment that bomb-pulse Cl-36 data found below the Paint Brush tuff can be linked to a negligible amount of fast flowing water (UZ 2.3.2).
DOE will evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts and transport. This evaluation will be documented in the UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006), Radionuclide Transport Models under Ambient Conditions (MDL-NBS-HS-000008) and Seepage Models for PA Including Drift Collapse AMR (MDL-NBS-HS-000002) expected to be available to NRC in FY 2003. DOE will also provide a technical basis for the assessment that bomb-pulse Cl-36 data found below the PTn can be linked to a negligible amount of fast flowing water. The technical basis will be documented in the UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006) expected to be available to NRC in FY 2003."

TEF 2.13: "Provide the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport AMR, Rev. 01 and the Analysis of Hydrologic Properties Data AMR, Rev. 01.
The DOE will provide updates to the Conceptual and Numerical Models for UZ Flow and Transport (MDL-NBS-HS-000005) Rev 01 and the Analysis of Hydrologic Properties Data (ANL-NBS-HS-000002) Rev 01 AMRs to the NRC. Scheduled availability is FY 02."

In summary, Agreement Items TSPAI 3.18, 3.21, and 3.23 address the following:

- The specific representation of nonlinear flow processes in the water-balance plug flow model particularly in areas of the repository where the soil is thin
- The effects of near surface lateral flow on the spatial variability of net infiltration
- The spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect of this heterogeneity on model results of unsaturated zone flow and transport
- The technical basis for the assessment of chlorine 36 found below the Paintbrush nonwelded unit can be linked to a small amount of fast-flowing water

The enclosed report provides risk information along with a discussion of the physical understanding of unsaturated zone (UZ) flow processes and corroborating lines of evidence as an alternative approach to closing these agreement items. The discussion is based on recent Total System Performance Assessment (TSPA) sensitivity studies, combined with the physical understanding of flow and transport in the UZ. This information shows that the treatment of uncertainty in these processes is sufficiently robust such that the information requested by the first three agreement items would not change the determination of whether or not the individual protection or groundwater protection standards of 10 CFR Part 63 would be met. While the technical information requested by the U.S. Nuclear Regulatory Commission (NRC) may add to the technical basis underlying the models for UZ flow and transport, the U.S. Department of Energy (DOE) believes the current representation of UZ flow and transport and its technical basis are adequate for evaluating compliance with the regulatory requirements of 10 CFR Part 63.

The fourth Agreement Item, TEF 2.13, requests revisions to two analyses and modeling reports. DOE believes that since the information in the enclosed report addresses the more specific requests in Agreement Items TSPAI 3.18, TSPAI 3.21, and TSPAI 3.23, it also addresses the underlying intent of Agreement Item TEF 2.13, which requests information on fracture flow and discrete fracture modeling.

Three comments in GENERAL (GEN) Agreement Item 1.01 had been identified as related to Agreement Item TSPAI 3.23. These comments are as follows:

> GEN 1.01.18: "Results of seepage into drifts shown in Table 5.3.1.4.2-2 after return to ambient conditions appear to be significantly different than the results from the Seepage Model for PA Including Drift Collapse AMR and seepage abstraction. What is the reason for these differences and how will the seepage abstraction incorporate this model-predicted range of variability?"
>
> GEN 1.01.24: "No data to support the conclusion that sub layers in the PTn might act as laterally continuous capillary barriers."
>
> GEN: 1.01.69: "The alternative modeling of flow through the PTn as discussed on p. 3-25 is based on the capillary pressure data of a single borehole. It seems that the conclusions use the implicit assumption that this single borehole (point) data is valid across the entire PTn layer. Spatial variability of this capillary pressure distribution could lead to very different modeling results. In particular, unless the spatial distribution of capillary pressures is not supported, the strong lateral flow component and resulting damping function of the PTn is not supported. On the contrary, lateral flow could be limited in scale, and result in localized flow focusing."
>
> "The conclusion in section 3.3.3.5 on p. 3-27, that the TSPA abstraction is conservative, is not supported. It is only conservative with respect to the presented simulation including lateral PTn flow over the entire layer. It could be non-conservative if lateral flow were found to be spatially limited, thus leading to a flow focusing within the PTn layer."

With respect to GEN 1.01.18, DOE responded that questions concerning the representation of heterogeneity, including the stochastic analyses methods used, will be addressed as part of the response to KTI Agreement Item TSPAI 3.23. Agreement Item TSPAI 3.23 provides information on the spatial heterogeneity of the hydrostratigraphic units. This information addresses GEN 1.01.18. The DOE believes Agreement Items GEN 1.01.24 and 1.01.69 are more appropriately mapped to Agreement Item *Unsaturated and Saturated Flow under Isothermal Conditions (USFIC) 4.04,* which will provide the final documentation for the effectiveness of the Paintbrush tuff to dampen episodic flow rather than TSPAI 3.23.

DOE considers TSPAI 3.18, 3.21, 3.23, TEF 2.13, and GEN 1.01.18 to be fully addressed by the enclosed report, and pending review and acceptance by the NRC, they should be closed. DOE intends to address GEN 1.01.24 and 1.01.69 in the response to USFIC 4.04.

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 Timothy C. Gunter at (702) 794-1343 or Mark C. Tynan at (702) 794-5457.

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

OLA&S:TCG-0379

Enclosure:
Licensing Letter Report, *Response to TSPAI 3.18, 3.21, 3.23, and TEF 2.13, REG-WIS-PA-000001, Revision 02*

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January 2003

KTI Letter Report

Response to TSPAI 3.18, 3.21, and 3.23, and TEF 2.13

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ENCLOSURE

KTI Letter Report—Response to TSPAI 3.18, 3.21, and 3.23, and TEF 2.13
REG-WIS-PA-000001 REV 02
January 2003

Prepared by:

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Decision Support and Documentation Department

Date

Checked by:

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Performance Assessment Strategy and Scope Project

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Decision Support and Documentation Department Manager

Date

CHANGE HISTORY

Revision Number	Interim Change No.	Effective Date	Description of Change
0	0	11/08/02	Initial issue.
1	0	12/04/02	Changes to add direct response to KTI agreement items; the major change is addition of a new section 2.1 and renumbering subsequent sections. Editorial changes made throughout; therefore, change bars not included. Also corrected version of SSPA cited.
2	0	1/20/03	Changes to respond to DOE Acceptance Review comments

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CONTENTS

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FIGURES

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ACRONYMS AND ABBREVIATIONS

AMR	Analysis/Model Report
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
ESF	Exploratory Studies Facility
KTI	Key Technical Issue
NRC	U.S. Nuclear Regulatory Commission
TEF	Thermal Effects on Flow
TSPA	total system performance assessment
TSPAI	Total System Performance Assessment and Integration
UZ	unsaturated zone
WBPF	water-balance plug-flow

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ACKNOWLEDGEMENT

The contribution of the Natural Barriers Project to Section 2.1 and the Natural Barriers Project and Engineered Barriers Project to Section 2.2 is acknowledged.

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1. INTRODUCTION

1.1 BACKGROUND

This response addresses Key Technical Issue (KTI) agreements Total System Performance Assessment and Integration (TSPAI) 3.18, 3.21, and 3.23 and Thermal Effects on Flow (TEF) 2.13. These agreements between the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) read as follows for the TSPAI agreements (Reamer 2001a) and the TEF agreement (Reamer 2001b):

TSPAI 3.18: "Provide a technical basis that the water-balance plug-flow model adequately represents the non-linear flow processes represented by Richard's equation, particularly over the repository where there is thin soil (UZ1.2.1). DOE will provide a technical basis that the water-balance plug-flow model adequately represents the non-linear flow processes represented by Richard's equation, particularly over the repository where there is thin soil. The technical basis will be documented in an update to the Simulation of Net Infiltration for Modern and Potential Future Climates AMR (ANL-NBS-HS-000032). The AMR is expected to be available to NRC in FY 2003."

TSPAI 3.21: "Demonstrate that effects of near surface lateral flow on the spatial variability of net infiltration are appropriately considered (UZ1.5.1). DOE will demonstrate that effects of near surface lateral flow on the spatial variability of net infiltration are appropriately considered in an update to the Simulation of Net Infiltration for Modern and Potential Future Climates AMR (ANL-NBS-HS-000032) and UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006). These AMRs are expected to be available to NRC in FY 2003."

TSPAI 3.23: "DOE should evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts and transport. DOE should also provide a technical basis for the assessment that bomb-pulse Cl-36 data found below the Paint Brush tuff can be linked to a negligible amount of fast flowing water (UZ2.3.2). DOE will evaluate spatial heterogeneity of hydrologic properties within hydrostratigraphic units and the effect this heterogeneity has on model results of unsaturated flow, seepage into the drifts and transport. This evaluation will be documented in the UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006), Radionuclide Transport Models under Ambient Conditions (MDL-NBS-HS-000008) and Seepage Models for PA Including Drift Collapse AMR (MDL-NBS-HS-000002) expected to be available to NRC in FY 2003. DOE will also provide a technical basis for the assessment that bomb-pulse Cl-36 data found below the PTn can be linked to a negligible amount of fast flowing water. The technical basis will be documented in the UZ Flow Models and Submodels AMR (MDL-NBS-HS-000006) expected to be available to NRC in FY 2003."

TEF 2.13: "Provide the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport AMR, Rev. 01 and the Analysis of Hydrologic Properties Data AMR, Rev. 01. The DOE will provide updates to the Conceptual and Numerical Models for UZ Flow and Transport (MDL-NBS-HS-000005) Rev 01 and the Analysis of Hydrologic Properties Data (ANL-NBS-HS-000002) Rev 01 AMRs to the NRC. Scheduled availability is FY 02."

These agreements relate to the technical basis for the representation of the unsaturated zone flow system, including the effects of spatial variability and heterogeneity on net infiltration and unsaturated zone flow and transport. The NRC has summarized comments in these areas in its *Integrated Issue Resolution Status Report* (NRC 2002, Section 3.3.5.4). First, the NRC commented that net infiltration may involve nonlinear processes and that the available data were insufficient to justify the use of a distributed-parameter, water balance plug flow approach to net infiltration in the face of such nonlinear processes. Second, the NRC commented that the effects of lateral surface or near-surface flow might be underestimated in the DOE net infiltration model. Third, the NRC commented that additional information is needed to show that heterogeneity within hydrostratigraphic units is not an important source of uncertainty. The NRC also requested revisions to analysis and modeling reports (AMRs) for unsaturated zone (UZ) flow and transport and analysis of hydrologic properties data (Reamer 2001b).

These issues apply to the current models for unsaturated zone flow, including net infiltration into the unsaturated rock and seepage into the emplacement drifts, and radionuclide transport in the unsaturated zone flow system. The technical basis for these models is considered to be adequate and documentation to this effect will be prepared for the License Application. The agreements here are to provide information in these specific areas prior to the License Application. In addition, since these agreements were made, total system performance assessment (TSPA) sensitivity studies have been conducted that provide additional insight into the significance of the uncertainty underlying the conceptual basis for the net infiltration model. In particular, these studies show that the treatment of uncertainties in the current representation due to nonlinear surface effects, variability, and heterogeneity is adequate for the assessment of compliance with the individual and groundwater protection requirements of 10 CFR 63.113 and for the description of barrier capabilities required by 10 CFR 63.115. This letter report therefore provides additional information regarding the sensitivity of total system performance to the net infiltration model to support closure of these KTI agreements.

1.2 PROPOSED RESOLUTION

These KTI agreements pertain to the technical basis and details of the unsaturated flow and transport components of the TSPA model. The technical basis for these model components was provided in the suite of Site Recommendation documents and will be updated in the suite of License Application documents. The agreements relate to the adequacy of the unsaturated zone flow model to address the effects of nonlinear near-surface processes on net infiltration; the effects of spatial variability on net infiltration and flow in the unsaturated zone; and the effects of heterogeneity in properties of the unsaturated rocks on unsaturated zone flow, seepage into emplacement drifts, and radionuclide transport in the unsaturated zone. The information to be provided, as called for in these agreements, could enhance the technical basis for the unsaturated zone flow and transport models used to estimate postclosure performance of the repository system.

The License Application work has been prioritized using a risk-informed approach. Accordingly, in responding to these four KTI agreements, information is provided in several areas to provide adequate assessment of the role of the unsaturated zone flow and transport in the assessment of risk. First, information is provided that directly addresses the questions of the technical basis for the net infiltration model addressed in these specific agreements. Second, the specific effects on the barriers to movement of water or radionuclides are discussed. Third, the sensitivity of the total system performance to bounding values of unsaturated flow and transport is calculated. The information in these areas augments the technical basis existing at the time the respective agreements were made and supports the conclusion that the model of net infiltration and unsaturated zone flow is adequate for the purposes of assessing total system performance.

The current technical basis for the unsaturated flow model is summarized in Section 2.1, with respect to the issues raised regarding the water-balance plug-flow (WBPF) submodel, near-surface lateral flow of water, the effect of heterogeneous hydrologic properties, and the effect of fast flow paths. The relationship of these effects to performance of the repository barriers is discussed in Section 2.2. In Section 2.3, the role of the repository barriers, as they are affected by the issues underlying these KTI agreements, in total system performance is summarized.

2. TECHNICAL BASIS FOR THE PROPOSED RESOLUTION

The unsaturated zone flow model is used to generate flow fields to predict the amount of flux and the transport of radionuclides in the unsaturated zone under various climatic conditions. The flow fields are developed based on the infiltration projected to occur over the next 10,000 years. Unsaturated zone flow can potentially affect the estimated amount of seepage into the emplacement drifts and the resulting amount of water that might contact the waste and mobilize radionuclides. Additionally, the unsaturated zone flow can affect transport of radionuclides that reach the rock in the unsaturated zone. The issues associated with the representation of unsaturated zone flow and transport therefore relate directly to whether this representation is adequate given its importance to the performance objectives of 10 CFR 63.113.

2.1 ISSUES REGARDING THE CURRENT MODEL OF NET INFILTRATION AND UNSATURATED ZONE FLOW

2.1.1 TSPAI 3.18

According to KTI agreement TSPAI 3.18, DOE will provide a technical basis for its conclusion that the WBPF model for infiltration into the unsaturated zone at Yucca Mountain adequately represents nonlinear processes described by the Richards equation. The technical basis is that: (1) the WBPF model incorporates spatial variability and model/data uncertainty, producing a wide range of values that is used in the TSPA; and (2) multiple lines of evidence show this range of net infiltration values is appropriate. Some of these results were obtained from alternative numerical modeling of unsaturated zone (UZ) flow and transport based on the Richards equation, which yielded or corroborated infiltration rates that are similar to those obtained with the WBPF model used in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001).

The current infiltration model estimates the spatial distribution of infiltration rates using the WBPF approach. The model was calibrated using discharge rates measured at stream gauges during 1994-95. For modern climate conditions the WBPF model results in a mean value for net infiltration of 4.7 mm/year over the repository area (USGS 2001, Section 6.11.1, Table 6-10). Net infiltration is calculated for an array of locations constituting a map of the site, taking spatial variability into account, such that the overall range of mean values for the map extends from 0 mm/year to 120 mm/year under the modern climate (USGS 2001, Table 6-10). In addition, alternative infiltration maps are generated for other climates (monsoon and glacial-transition) and other areas surrounding the repository (USGS 2001, Sections 6.11.1 through 6.11.3).

Approaches to the estimation of recharge rates are summarized in a recent study of (Flint et al. 2002), which compares the WBPF model with other methods including

- Darcian approaches in which liquid flux is evaluated from the heat and moisture transport equations
- Neutron logging of moisture profiles
- Empirical methods in which recharge measurements are correlated with precipitation measurements
- A variety of environmental tracer methods in which the net infiltration rate is estimated from concentrations and age-dating information
- Borehole temperature profiles.

The review compares the ranges of recharge and net infiltration rates estimated in the different approaches (Flint et al. 2002, Figure 9). These estimates support the upper bound limits on infiltration rates and percolation fluxes used in the TSPA model. The following summarize the results for some of these approaches:

- ***Chloride mass balance.*** Net infiltration rates can be inferred from the chloride concentration in waters sampled from the unsaturated zone, relative to that in the precipitation on Yucca Mountain. Meteoric chloride is used as a conservative tracer that represents the time-averaged result of surface and near-surface infiltration processes, and of percolation in the unsaturated zone. Percolation flux in the unsaturated zone has been shown to be similar to net infiltration at the surface (Section 3.7.4.1 and Table 3.7-4, CRWMS M&O 2000c); hence, the composition of waters sampled from the unsaturated zone may be used to quantify net infiltration as well as percolation. Maps of chloride concentration in such waters suggest net infiltration fluxes of 1 to 1.5 mm/year on the low east slope of the site area, 2.5 to 3 mm/year on the mid-level east slope, and about 7 mm/year at the crest (Section 3.8.2, Figure 3.8-3 [fluxes], and Figure 2.4-4 [topography], CRWMS M&O 2000c). These values are within the range of the water-balance plug-flow model results. In addition, chloride concentrations were predicted for water samples from the welded tuff units penetrated by the Enhanced Characterization of the Repository Block (ECRB) cross-drift. These predictions are comparable to the observed concentrations (Figure 3.8-7, CRWMS M&O 2000c), adding confidence to the infiltration model as it is implemented in the UZ flow model.
- ***Calcite deposition.*** Calcite abundances in fractures, combined with age dating to estimate rates of deposition, suggest a percolation flux in the range of 2 to 20 mm/year at Yucca Mountain (Section 4.2.1.3.1.5, DOE 2002), based on a natural system that has evolved over millions of years. At borehole USW WT-24, the calcite deposition suggests

a flux of about 6 mm/year (Figure 4-14b, DOE 2002), which compares with the average at this location of approximately 10 mm/year from the infiltration model incorporating plug-flow (Section 3.8.2 and Figure 3.8-4 [Region I], CRWMS M&O 2000c).

- *Perched water.* Stable perched water bodies encountered in several boreholes have been evaluated using chemical and isotopic data, and simulated in 3-D using the UZ flow model. The preliminary results of this evaluation show that the average net infiltration flux is in the range of 1 to 15 mm/year (Section 3.7.4.5, CRWMS M&O 2000c). This range corroborates the WBPF model results for present-day climate conditions.

- *Temperature profiles.* Comparison of measured temperatures at depth with results of a one-dimensional model suggests a percolation flux in the range of 10 to 20 mm/year (Rousseau et al. 1999, p. 190). These values are within the range of the WBPF model results.

- *Heat flow anomaly.* Yucca Mountain is within a regional heat-flow deficiency that can be explained by a percolation flux between 2 and 5 mm/year (Sass et al., 1988, p. 47, data pertaining to percolation rather than net infiltration). These values are within the range of the WBPF model results.

- *Regional water budget.* Recharge to various drainage basins in the area has been estimated using the Maxey-Eakin method. For the Pahute Mesa groundwater system, the estimated recharge is about 2.4 mm/year, about 1 percent of precipitation. (Rush 1971). Closer to Yucca Mountain, recharge at Buckboard Mesa is estimated to be 2.8 mm/year, at Jackass Flats to be 1.5 mm/year, at Crater Flat to be 0.6 mm/year, and at Oasis Valley to be 1.1 mm/year (Rush 1971 [calculated from Table 3 without "other areas"]). These values are within the range of the water-balance plug-flow model results. Watson et al. (1976) used the Maxey-Eakin transfer function approach to estimate net infiltration for basins in Nevada. They found that for precipitation rates between 0 and 300 mm/year, less than 3 percent becomes net infiltration, further substantiating the infiltration model for Yucca Mountain.

These independent lines of evidence indicate the representativeness of the net infiltration rate estimated in the WBPF model. This model is consistent with physical results of the processes that have evolved through geologic time. Included in these physical results are the effects of the nonlinearities, heterogeneities, and other process level details that have occurred. Although the model does not explicitly calculate all effects of nonlinearity and heterogeneity, it nevertheless matches the observed infiltration results and is an adequate representation of the Surficial Soils and Topography barrier performance. Even though uncertainty in the underlying infiltration processes due to potential nonlinear effects has not been removed, the independent lines of evidence corroborate the applicability of the model. The importance of the uncertainties to assessment of total system performance is considered in Sections 2.2 and 2.3.

2.1.2 TSPAI 3.21

According to KTI agreement TSPAI 3.21, DOE will demonstrate the effects of near-surface lateral flow on spatial variability of net infiltration are adequately considered. The effects of near-surface lateral flow on the spatial variability of net infiltration are dependent upon a number of variables, including the intensity and duration of precipitation, the thickness of soil cover, the degree of bedrock fracturing, the permeability of the fractures, the slope of the ground surface, the prevailing temperature, and the evapotranspiration potential. Accordingly, the infiltration model (Sections 6.1 - 6.4, USGS 2001) incorporates such considerations in its evaluation of the potential for generating runoff (near-surface lateral flow) from one model grid cell to another and thereby inducing spatial variability of net infiltration.

The model used to predict net infiltration includes instantaneous flow routing, which produces substantially increased values for local net infiltration in washes where lateral flow converges (Section 6.11.1, USGS 2001). Water mass balance between precipitation, net infiltration, evapotranspiration, run-off, and run-on is conserved. Maximum net infiltration is correlated with maximum surface run-on, indicating that the model adequately captures the importance of lateral surface flow relative to other terms in the mass balance such as evapotranspiration. In addition, run-on and run-off are calculated at the boundaries of the UZ flow model domain (Section 6.11.1, USGS 2001), particularly in washes where run-on is most significant, further contributing to adequate representation of net infiltration.

More detailed treatment of lateral surface flow is possible as discussed in the model documentation (e.g., implementation of partial differential equations for surface flow; Section 6.4.7, USGS 2001). However, any difference in the predicted daily average infiltration that such treatment might produce would be of secondary importance because the nonwelded Paintbrush tuff layer in the UZ above the repository horizon moderates such focused, episodic flow. The nonwelded Paintbrush tuff layer thickness ranges from 30 m to 60 m in the repository area (Section 3.7.3.1, CRWMS M&O 2000c), and fracture-dominated percolating flow from the surface to the Tiva Canyon welded tuff changes to matrix-dominated in the underlying nonwelded Paintbrush tuff. The UZ flow model accounts for the moderating effects of this layer, including some lateral diversion (Section 3.7.3.1, CRWMS M&O 2000c).

The multiple lines of evidence summarized above for TSPAI 3.18, and the conclusions about the adequacy of the representation of the Surficial Soils and Topography barrier, also apply for the issue of near-surface lateral flow. Such lateral flows influenced development of the total chloride distribution, calcite distribution, temperature distribution, and perched water, and these influences are captured in the measurements of the parameters that are used to evaluate the representation of the barrier. The results suggest that the variability in the representation of net infiltration used in the TSPA model is reasonable. Uncertainties exist in this representation including the effects of possible enhancements in the representation of surface lateral flow. The importance of these uncertainties is considered in Sections 2.2 and 2.3.

2.1.3 TSPAI 3.23

According to KTI agreement TSPAI 3.23, DOE will evaluate the effects of spatial heterogeneity of hydrologic properties of the unsaturated hydrostratigraphic units on the estimates of seepage and radionuclide transport. In addition, DOE will provide the technical basis for its representation of the amount of fast flowing water in the UZ flow system.

Spatial Heterogeneity

The model for UZ flow includes spatial variability of net infiltration, variation in hydrostratigraphic unit properties, explicit representation of faults, and representation of major facies changes in the CHn unit that affect flow and transport. Flow from the surface to the repository is gravity dominated, as shown above in the discussion of the similarity between percolation and net infiltration. Accordingly, spatial heterogeneity within hydrostratigraphic units is unimportant to the distribution of vertical flux, because these units have vertical unsaturated hydraulic conductivity that is in excess of that needed to support free drainage. The unsaturated flow model, the seepage model, and the seepage abstraction model include the following features that represent the important aspects of spatial heterogeneity:

- In the UZ flow model, percolation flux ranges from approximately 1 to 60 mm/year (spanning the present-day, monsoonal, and glacial-transition climate states; Figure 3.7-2, CRWMS M&O 2000c).

- The seepage model was calibrated to field tests that incorporated effects from spatial heterogeneity at the scale of a few meters or less in Niche 3650 (middle nonlithophysal tuff; Section 3.9.4, CRWMS M&O 2000c).

- As input to the drift seepage abstraction model, the local percolation flux in the host rock was further increased by a focusing factor (varying stochastically from 1 to an upper limit ranging between 9.7 and 47, depending on the representation of uncertainty in the net infiltration; see Section 3.9.6.3, CRWMS M&O 2000c) to represent the effects of spatially heterogeneous flow conditions.

- The drift seepage process model (Section 3.9.5.2, CRWMS M&O 2000c) is based on flow simulations with random, spatially heterogeneous properties to represent the fracture network.

- The drift seepage abstraction model for TSPA uses uncertainty distribution functions to capture uncertainty and spatial variability of key parameters (Section 3.9.6.4 and Table 3.9-2; CRWMS M&O 2000c).

The spatial distributions of vitric and zeolitic material with the Calico Hills non-welded stratigraphic unit are important for understanding the distribution of perched water and for determining potential flow paths for radionuclides. The Calico Hills layers (and the lowest Topopah Spring welded tuff layer) have been altered from vitric to zeolitic in some areas and remain unaltered in other areas.

The principal differences between zeolitic and vitric tuff are the saturated hydraulic conductivity for flow and the sorptive properties for transport. The saturated hydraulic conductivity for vitric tuff is three or more orders of magnitude higher than that of zeolitic tuff. The vitric tuff also has low (<~90%) matrix saturations as compared with zeolitic tuff matrix (>90%). Furthermore, the porosity of zeolitic tuff matrix has been found to be sensitive to the laboratory rock drying process. For zeolitic rock, oven-dried (105°C) samples have substantially larger porosities than samples dried under controlled relative-humidity conditions, whereas for vitric rock, the range of porosities from the different drying processes is less than 5%.

Cores from boreholes covering the site-scale model domain have been analyzed, and the differences in vitric and zeolitic rock characteristics have been used to define vitric and zeolitic zonation in the UZ site-scale model grid (BSC 2001b). The variation in hydrogeologic properties for vitric and zeolitic rock is included in the UZ flow model calibration (CRWMS M&O 2000a). Differences in sorptive properties for vitric and zeolitic rock are included in the sorption model used for radionuclide transport (BSC 2001c).

To summarize the above discussion, the effects of spatial heterogeneity observed at Yucca Mountain have been evaluated and taken into account in the TSPA model. The effects of the associated uncertainty and variability on the assessment of total system performance are considered in Sections 2.2 and 2.3.

Fast Paths

Observations of bomb-pulse ^{36}Cl in the Exploratory Studies Facility (ESF) indicate that some fast paths (transport times less than 50 years) from the ground surface to the potential repository level exist. The original bomb-pulse ^{36}Cl observations were found in only a few locations that generally correlate statistically with fault features that cut through the nonwelded Paintbrush tuff unit above the repository horizon (Section 3.8.3, CRWMS M&O 2000c). These observations support the current understanding that only a small fraction of the total flow in the UZ moves along these fast paths, for the following reasons:

- Bomb-pulse samples are found in only a few locations in the ESF. In samples from the tunnels, no evidence has been found for pervasive fast flow pathways that are not associated with faults or fracture zones. These discrete fast paths are not associated with large catchment areas involving large volumes of infiltrating water (Section 3.3.7, CRWMS M&O 2000c).

- Bomb-pulse signatures of ^{36}Cl were not found in the perched waters. Nuclear-age tritium was detected in only one sample of perched water (in borehole NRG-7a) but not in any of the other samples (Section 3.3.7, CRWMS M&O 2000c).

The ^{14}C apparent ages of the perched water are on the order of thousands of years (Sections 3.8.2 and 3.8.3, CRWMS M&O 2000c). This is reconciled with the observations of bomb-pulse ^{36}Cl at the ESF level using a conceptual model in which rapid movement of a small amount of water (yielding the ^{36}Cl observations) is mixed with a relatively large flux of much slower-moving water (that dominates the ^{14}C signal in perched water). Predictions from the UZ flow model are consistent with this conceptual model. Breakthrough at 50 years (i.e., of bomb-pulse ^{36}Cl) correlates with faulted locations and is on the order of 1% of the initial infiltration (Section 3.11.8 and Figure 3.11-9 Simulation 1 [tracer source over the central area, applied as a time zero pulse], CRWMS M&O 2000c). This conservative model comparison increases confidence in the UZ flow model, even though flow in the UZ above the repository does not significantly affect TSPA calculations.

Knowledge of the existence of fast pathways has guided the development of the UZ flow conceptual model to include dual-permeability concepts that can capture the range of travel times corresponding to flow in the matrix and flow in fractures. The quantitative ^{36}Cl information has been compared with the numerical results of the model. However, questions remain as to the interpretation of ^{36}Cl measurements. Accordingly, the information is used as "supporting data" rather than as a target for model calibration. Even though the ^{36}Cl data were not used to calibrate the unsaturated flow model (Section 3.7.4.4, CRWMS M&O 2000c), the distribution of travel times predicted by the model is consistent with the data.

In addition, the ^{36}Cl observations are taken as evidence for possible fast pathways from the repository to the water table (Section 3.11.8, CRWMS M&O 2000c). Breakthrough curves calculated with the UZ flow and transport model cover this possibility. For the present-day climate, fractional breakthrough at the water table at 50 years ranges from nearly zero to approximately 12% (Section 6.12.2 [assuming the similarity of non-sorbing Tc and Cl] and Figure 6.12-1, BSC 2001d) for the low, mean, and high alternative infiltration rates. The mean infiltration rate 50 year fractional breakthrough is approximately 3%. For wetter, future climate conditions, the predicted fractional breakthrough at 50 years is greater (Figures 6.12-22 and 6.12-23, BSC 2001d). Hence the spatial heterogeneity and conceptual uncertainty associated with the ^{36}Cl are included in the UZ flow and transport calculations supporting TSPA.

2.1.4 TEF 2.13

According to KTI agreement TEF 2.13, DOE will provide the AMRs for UZ flow and transport and for analysis of hydrologic properties data. The request for the UZ flow and transport AMR was based on projected additional work on fracture flow under ambient and thermal conditions. The request for the analysis of hydrologic properties data AMR was based on projected additional work on discrete fracture modeling.

In planning for development of the License Application, the overall work scope for performance assessment and the supporting process models was prioritized and re-planned, using a risk-informed approach. A systematic decision-aiding method was used to ensure that the full implications of various work scopes for all component models were considered and evaluated (Swift 2002). In the prioritization process, additional work on fracture flow under ambient and thermal conditions and on discrete fracture modeling was given a low priority because further work would not be likely to result in predicted changes that are adverse to repository system performance. Accordingly, the additional work was not included in the current plan and will not be completed for the License Application.

The information in this letter report pertains to the three TSPAI KTI agreements discussed above, which also addresses the underlying intent of the TEF 2.13 KTI agreement. For example, as noted in Section 2.1, the effects of spatial heterogeneity in the hydrologic properties observed at Yucca Mountain have been evaluated and taken into account in the TSPA model. In addition, the drift seepage model (Section 2.1) is based on flow simulations with random, spatially heterogeneous properties to represent the fracture network. Therefore, this information bears directly on those spatial heterogeneities related to discrete fractures and fracture flow under ambient and thermal conditions.

2.2 PHYSICAL RELATIONSHIP OF THESE ISSUES TO PERFORMANCE OF REPOSITORY BARRIERS

The issues that underlie these KTI agreements pertain to the representation of the unsaturated zone flow system, including the effects of spatial variability and heterogeneity on net infiltration and unsaturated zone flow and transport. The relative importance of these issues depends upon their effect on the natural and engineered barriers of the repository system. Relevant barriers include the Surficial Soils and Topography, the Unsaturated Zone Above the Repository Horizon, the Drip Shield, the Waste Package, the Cladding, the Waste Form, the Drift Invert, and the Unsaturated Zone Below the Repository Horizon. The roles of the issues associated with these KTI agreements, with respect to the capabilities of these barriers to limit the movement of water or radionuclides, are summarized in the following:

- If the Surficial Soils and Topography barrier were less effective than expected, the higher flows of water would pass through the downstream barrier, the Unsaturated Zone Above the Repository Horizon, and result in higher volumes and areas of seepage.

- Increased seepage means that a larger fraction of the Drip Shield barriers would be in an aqueous (rather than humid air) environment for more of the time.

- In the event of drip shield failure from either corrosion or mechanical loads, increased seepage also means that a larger fraction of the Waste Package barriers would be in an aqueous (rather than humid air) environment for more of the time. However, the available data from the Long Term Corrosion Facility show that general corrosion rates for titanium and alloy 22 are similar in aqueous and humid air environments, implying that higher seepage would not affect drip shield and waste package lifetimes (CRWMS M&O 2000e, Section 6.9, and CRWMS M&O 2000f, Section 6.2). Data obtained on Alloy 22 after 5 years of exposure also support this observation.

- Increased seepage could also result in a change in the chemistry of the aqueous film on the drip shield and waste package, and could also locally and temporarily change the temperature of these surfaces. However, this change would be expected to make the environment more benign because of dilution and also because of the presence of corrosion inhibiting anions (e.g. nitrate) in seepage that has had prolonged prior contact with the host rock.

- Other corrosion modes, such as localized corrosion and stress corrosion cracking, are not sensitive to increased seepage. Under the current models of Alloy 22 and titanium for localized corrosion, conditions required for localized corrosion would not be reached under the expected repository conditions (CRWMS M&O 2000d, Sections 5.3 and 5.4). With increased seepage, the environment is expected to become more benign due to dilution and presence of favorable anions as noted above.

- The next downstream barriers are the Cladding and Waste Form, which limit the mobilization of radionuclides, a second potential aspect of a barrier as defined in 10 CFR 63.2. The discussion below focuses on the relationship between dose and infiltration for both the nominal scenario (which has intact drip shields and only a single waste package early failure) and the igneous intrusion scenario, which has a significant number of (co-located) failed waste packages and drip shields.

- Finally, increased infiltration results in increased transport in the Drift Invert and Unsaturated Zone Below the Repository Horizon barriers. Limitation of transport of radionuclides is the third potential aspect of a barrier defined in 10 CFR 63.2. Section 2.3 discusses the sensitivity of dose to the Unsaturated Zone Below the Repository Horizon transport barrier, which would be a downstream effect of the infiltration model (TSPAI 3.18 and 3.21) and in the UZ flow and transport model (TSPAI 3.23).

2.3 IMPORTANCE OF THESE ISSUES TO TOTAL SYSTEM PERFORMANCE

The potential effect of flow and seepage uncertainties on mobilization and transport of radionuclides depends upon the entire scenario of processes and events affecting release of radionuclides from the repository system. There are two scenarios in which the UZ flow plays a role: the nominal scenario (the scenario for expected conditions in which igneous activity does not occur) and the igneous activity groundwater release scenario. The nominal scenario describes expected conditions for the elements of the system. Disruptive events such as those associated with igneous activity are not considered. The radionuclides that dominate the estimate of mean annual dose for this scenario (e.g., technetium-99) are highly soluble (CRWMS M&O 2000b, Table 3.5-8, p. 3-119) so that their release does not depend strongly on the amount of water that is present. Uncertainties in the representation of the flow system are therefore not likely to have a significant effect on the estimate of mean annual dose for the nominal scenario.

In the igneous activity groundwater release scenario, igneous activity occurs and intruding magma damages waste packages and drip shields in a portion of the repository, exposing the waste to water moving down through the UZ. In this scenario, the affected part of the repository does not benefit from diversion of water from the waste by the drip shields and waste packages. Consequently, the significance of variations and uncertainties in the UZ flow system may be more clearly ascertained. The radionuclides that dominate the estimate of the probability-weighted mean annual dose for the igneous activity groundwater release scenario include radionuclides that are less soluble (e.g., neptunium-237, plutonium-239, and plutonium-240). The release of these radionuclides could be affected by the amount of water present, and details of the flow model could translate into effects on the estimate of mean annual dose. However, the amount of water contacting the waste in the next 10,000 years cannot be greater than the maximum amount of precipitation that might fall onto Yucca Mountain over that period. The current model provides conservative estimates of the amount of water that might reach the repository horizon and seep into emplacement drifts and yet results in estimates of mean annual dose that are orders of magnitude below the regulatory standard.

Consequently, even assuming that the maximum amount of water impinging on Yucca Mountain is able to contact the waste, the estimate of mean annual dose is unlikely to reach a significant level. Specific quantitative estimates in this regard are discussed in Section 2.3.

The flow and transport barrier below the repository horizon delays the arrival of radionuclides at the accessible environment. This delay is due to processes that affect the movement of radionuclides through the rock. These processes include matrix diffusion, sorption, and colloid filtration. In addition, the contaminated fluid originating from the point source (the failed waste package) is dispersed laterally as it moves, is dispersed longitudinally due to the distribution of water velocities, and is diluted as it mixes with the water that bypassed the failed waste package. Section 2.3 quantitatively discusses the contribution of transport delay in the natural barriers to compliance with the individual protection requirement.

Three TSPA sensitivity studies have been conducted to quantify these barrier contributions to total system performance. The studies have been conducted using a TSPA model described in *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002, Section 3.1). In the first sensitivity study, the results using the current UZ flow model are compared to the results using a bounding representation for the UZ flow. Precipitation onto Yucca Mountain averages about 190 mm/year under current conditions, and the maximum average is estimated to be no more than 310 mm/year over the next 10,000 years (BSC 2001a, Table 3.3.1-1, p. 3T-1). The corresponding net infiltration flux in the current model averages about 4.7 mm/year under present day conditions and about 12.5 mm/year over the next 10,000 years (USGS 2001, Tables 6-10 and 6-14). The flux in the bounding model considered in the sensitivity analysis averages about 150 mm/year (BSC 2001a, Table 3.3.2-3, p 3T-7), more than an order of magnitude greater than the average infiltration flux of the current model and only a factor of 2 below the maximum of the average annual precipitation projected for the next 10,000 years. Thus, these two representations provide a wide range over which to examine effects of model uncertainty on estimates of postclosure performance.

Estimates of mean annual dose for the two modeled infiltration fluxes are shown in Figure 1 herein. The estimate of mean annual dose for both infiltration fluxes, in the nominal scenario, is dominated by soluble radionuclides, carbon-14, technetium-99, and iodine-129. The change in mean annual dose in the first 10,000 years for these radionuclides is estimated to be less than 0.0001 mrem and is insignificant when compared to the standard of 15 mrem.

The release for the igneous activity groundwater release scenario is dominated by solubility-limited radionuclides, neptunium-237, plutonium-239, and plutonium-240, and the estimate of mean annual dose is higher than for the nominal scenario. Nevertheless, the change in the mean annual dose in the first 10,000 years is less than 0.01 mrem and is insignificant in comparison with the 15 mrem standard.

This sensitivity study includes the far field effect of increased infiltration but does not include near-field effects such as increased seepage into the emplacement drifts. A second study addresses the effects of increased seepage that may be associated with higher infiltration. Figure 2 herein compares the results for the current model with the results for a bounding model for seepage. The current model results in zero seepage over approximately half the waste packages and an average seepage flux that is less than 0.1 m^3/year over the other waste packages (*BSC* 2001a, Table 4.3.1-1, p. 4T-1). The bounding model considers the effect of seepage of 1 m^3/year over the location of every waste package, an average of nearly a factor of 20 greater than that of the current model. These two models, therefore, encompass a range comparable to the range of infiltration flux considered in the previous sensitivity study.

The results for the nominal scenario show no significant difference in the first 10,000 years. Two factors determine this small effect. The first is that the drip shield remains intact in this scenario and increases in the flux do not directly lead to increased flux through breached waste packages. As a result 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 is somewhat higher for the igneous activity groundwater release scenario. Because drip shields are damaged in this scenario, 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, still insignificant in comparison with the regulatory standard of 15 mrem.

A third sensitivity study examines the effect of different representations of the flow system on transport more directly. The results are shown in Figure 3 herein. This figure compares the results for the UZ and saturated zone transport systems as modeled in the current approach to the results using bounding models to represent flow and transport in these systems. The first bounding model computationally neutralizes the transport system entirely (i.e., radionuclides released from the engineered barrier system are assumed to be directly discharged to wells in Amargosa Valley). Thus, the bounding model excludes assumptions about the characteristics of the flow and transport system (e.g., assumptions about whether radionuclide transport in the fractures or the matrix is diffusive or advective; or about sorption, colloid filtration, or matrix diffusion). The results show release from the system in the early period since transport delays associated with the natural system have been computationally neutralized. However, the mean annual dose associated with these releases is less than 1 mrem and is small compared to the standard of 15 mrem. Therefore, uncertainties in the representation of UZ flow and transport are not likely to have an important effect on determining if the individual protection standard is met (since these uncertainties would lead to changes much smaller than 15 mrem).

Comparison of the above results is also made in Figure 3 herein with the flow system characteristics included but with the transport characteristics excluded from the model. The results are not significantly different from those in which the entire flow and transport system is ignored. Thus, it can be inferred from the comparison that the representation of the UZ flow alone does not have a significant effect on the estimate of mean annual dose.

The results of these three sensitivity studies confirm the barrier contributions to repository performance discussed in Section 2.1. The results show little sensitivity of total system performance in the nominal scenario to the particular representation of infiltration of moisture into Yucca Mountain because the dominant radionuclides in this case are soluble and insensitive to the amount of water contacting the waste. Accordingly, the precise representation of nonlinear effects and heterogeneity in that representation is not expected to play an important role in determining compliance with the individual and groundwater protection requirements. The results for the igneous activity groundwater release scenario do show some sensitivity to the amount of water contacting the waste and transporting radionuclides away from the repository. However, the potential effects on the estimate of mean annual dose are minor because the estimates are small and the range of uncertainty in the infiltration is limited by physical constraints. If the infiltration were comparable to bounding levels of precipitation (~10 m/year), a linear extrapolation of the results shown in Figures 1 and 2 herein would result in estimated doses below the individual protection standard.

3. CONCLUSION

The technical basis for the treatment of near-surface nonlinear processes, spatial variability, and heterogeneity in properties of the UZ rocks (including their implications for fast flow paths) in the UZ flow and transport model 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 UZ barriers 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 results presented in Section 2.3, which consider both the current model and bounding representations of net infiltration and UZ flow, indicate that uncertainties in the representation of the UZ flow system described in these KTI agreements do not play a significant role in determining whether the individual protection requirement would be met. Similar conclusions would be drawn with respect to the determination regarding the groundwater protection 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 are provided to satisfy agreements TSPAI 3.18, 3.21, and 3.23, and TEF 2.13.

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4.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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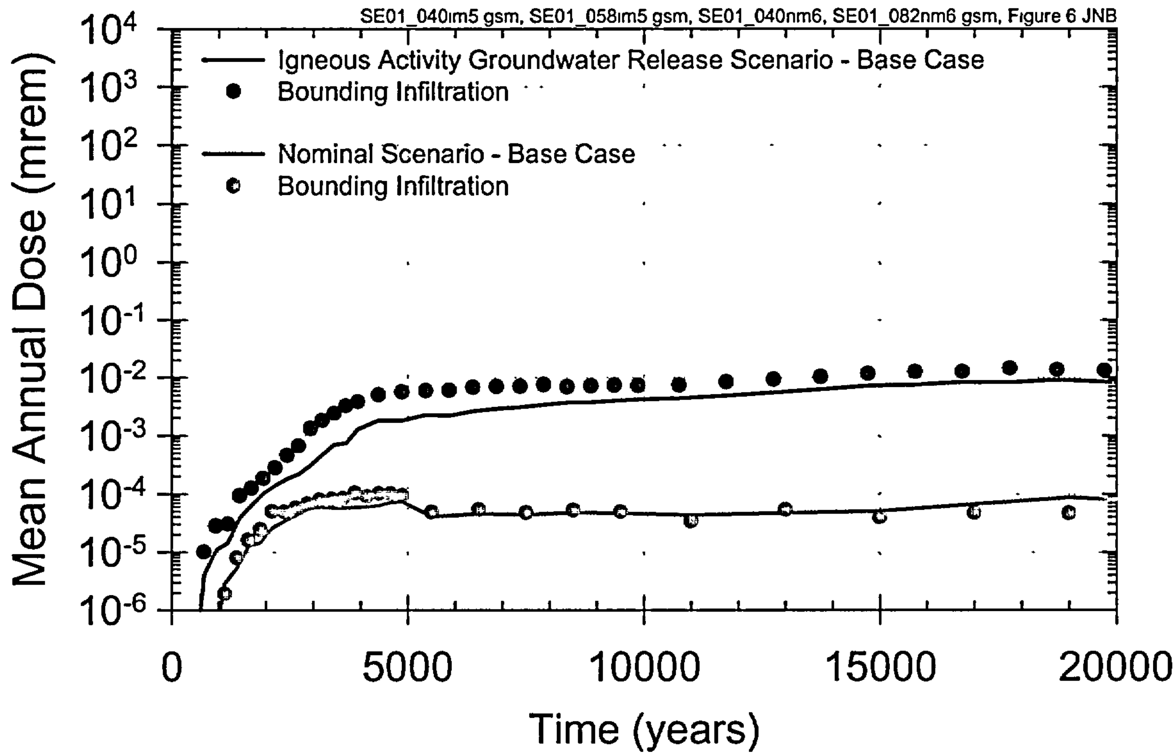
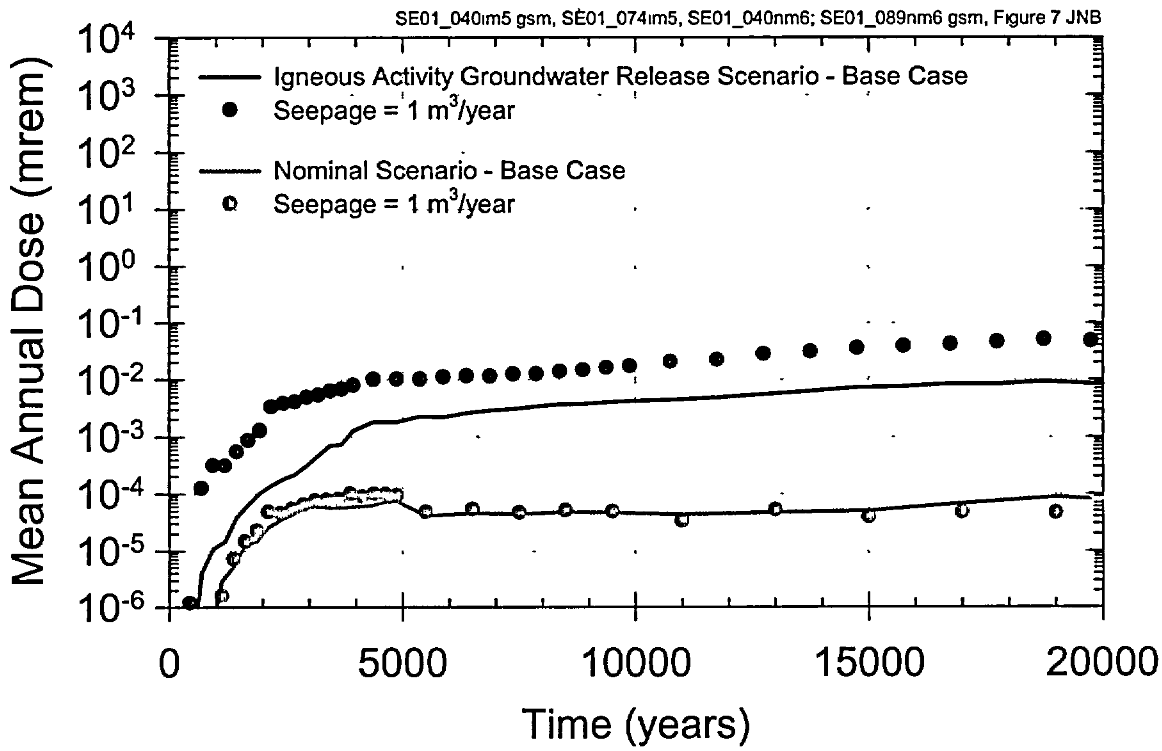


NOTES:
1. Each mean annual dose curve is a probability-weighted average.
2. The results in this figure are adapted from Figure 6 of *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002).
3. The model for the nominal scenario includes one waste package that is failed early due to improper heat treatment. None of the other waste packages fail before 10,000 years because corrosion rates are low. The model for the igneous activity groundwater release scenario assumes that magma damages a number of waste packages and drip shields. The number is a probability distribution that averages 300.

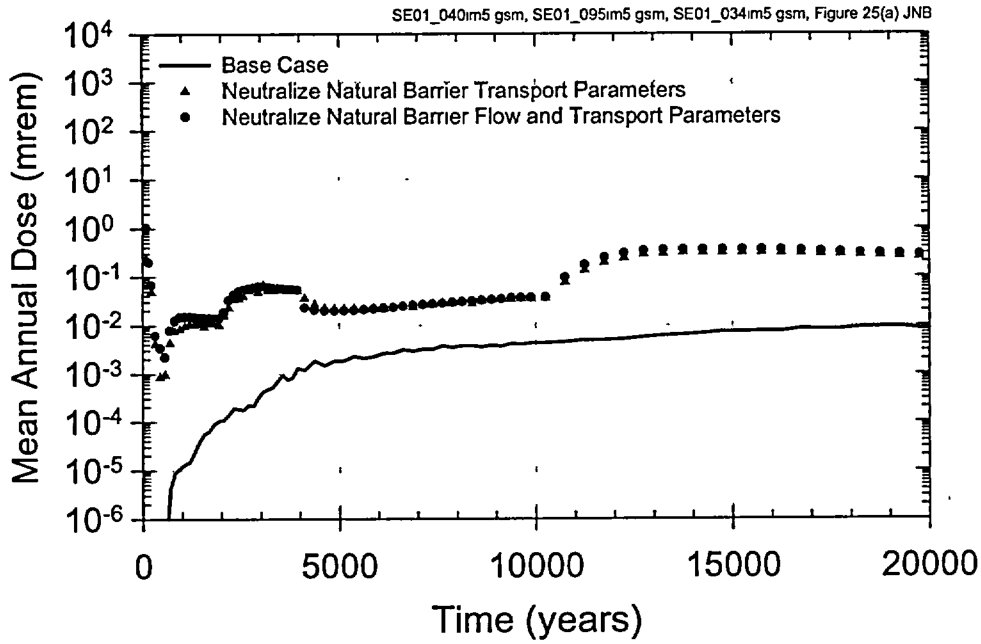
Figure 1 Sensitivity of Mean Annual Dose to the Unsaturated Zone Flow Model as Defined for Base-Case and Bounding Infiltration Fluxes



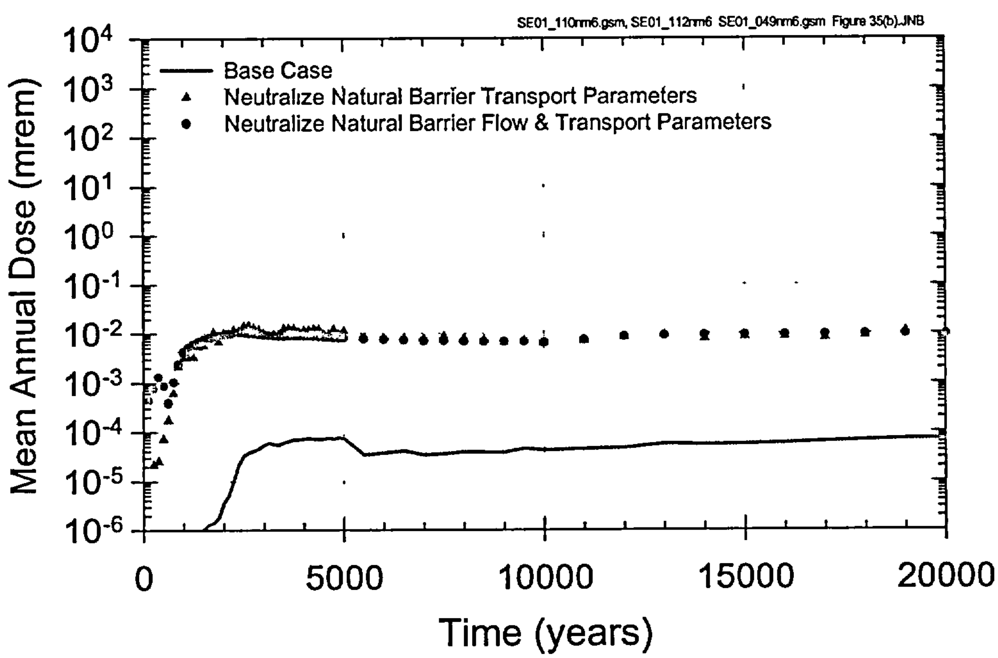
NOTES:
1. Each mean annual dose curve is a probability-weighted average.
2. The results in this figure are adapted from Figure 7 of *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002).

Figure 2 Sensitivity of Mean Annual Dose to the Seepage Model

(a) Igneous Activity Groundwater Release Scenario



(b) Nominal Scenario



NOTES:
1. Each mean annual dose curve is a probability-weighted average.
2. The results in this figure are adapted from Figure 35 of *Risk Information to Support Prioritization of Performance Assessment Models* (BSC 2002).

Figure 3 Sensitivity of Mean Annual Dose to Full Computational Neutralization of the Unsaturated Zone and Saturated Zone Flow and Transport Barriers and to Computational Neutralization of Only the Transport Parameters.