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COMPARISON OF REFERENCE INPUT PARAMETER VALUES FOR THE TOTAL SYSTEM PERFORMANCE ASSESSMENT OF THE PROPOSED YUCCA MOUNTAIN REPOSITORY

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ABSTRACT

As part of prelicensing activities, the Nuclear Regulatory Commission (NRC) and the Center for Nuclear Waste Regulatory Analyses (CNWRA) conduct reviews of the U.S. Department of Energy (DOE) performance assessments (PA) for the proposed high-level waste repository at the Yucca Mountain site. To date, the DOE has published a series of three total system performance assessments (TSPAs) for the proposed repository, with each successive iteration using updated model abstractions and incorporating additional site characterization data. The NRC and the CNWRA conducted both audit and detailed reviews of the DOE TSPAs to provide commentary and early feedback to the DOE regarding defensibility of the performance models and adequacy of site characterization data. This feedback has been presented to the DOE via written comments, technical reports (available in the NRC Public Document Room), and in technical exchange meetings.

Currently, the DOE is preparing for the conduct of a comprehensive TSPA that will support their Viability Assessment (VA) for the proposed repository. This TSPA iteration, expected to be completed in September 1998, will be given an in-depth and probing technical review by the NRC. In preparation for such a review, the NRC/CNWRA has updated its PA computer code, designated as TPA (acronym for Total-system Performance Assessment).This latest version of the TPA code supersedes the computer code originally developed for the NRC Iterative Performance Assessment (IPA) Phase 2 study (Nuclear Regulatory Commission, 1995). The new version of the TPA code (Version 3.1) incorporates updated model abstractions developed as part of the work on NRC key technical issues (KTIs) and (i) accommodates the most recent DOE reference repository and waste package designs, (ii) has the capability to incorporate recent site characterization data, and (iii) provides the capability to estimate performance measures (e.g., individual dose) which may be specified in the revised regulatory standards (National Academy of Science, 1995). In addition, the TPA Version 3.1 code will be used for system-level sensitivity analyses. The TPA Version 3.1 code is expected to be used in the NRC IPA Phase 3 study and the input parameter values for the code are proposed to be the reference parameter values in the IPA Phase 3 study.

In preparation for the sensitivity analyses, the CNWRA is compiling a reference (or base case) set of parameter values. The sources for the reference set of parameter values are: (i) data available in DOE databases, (ii) parameter values used in TSPA-95 (TRW Environmental Safety Systems, Inc., 1995), (iii) parameter values used in NRC IPA Phase 2, (Nuclear Regulatory Commission, 1995), and (iv) best estimates of NRC/CNWRA staff. The DOE is likely to update its parameter values for TSPA-VA. A comparison of current NRC/CNWRA thinking about parameter values, and those used in DOE TSPA-95 indicate the following main differences.

- TSPA-95 used infiltration rates of 0.5 to 2.0 mm/yr in contrast to the proposed IPA Phase 3 reference values of 1.0 to 10.0 mm/yr

- TSPA-95 used a funnel factor (a factor determining flow channeling into emplacement drifts) of 4 while the IPA Phase 3 parameter value is proposed to be less than 1.0

- TSPA-95 used solubility values for a number of radioelements (e.g., curium, cesium, selenium, and technetium) that are smaller than currently proposed to be used as reference values in IPA Phase 3.

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- TSPA-95 used radionuclide sorption coefficients for a number of radioelements (e.g., americium, cesium, radium, and technetium) that are higher than those currently proposed to be used as reference values for IPA Phase 3; in contrast, TSPA-95 used lower sorption coefficients for two radioelements (e.g., niobium and lead).

The DOE recently indicated they intend to use higher infiltration rate values in their TSPA-VA, comparable to those proposed to be used as reference values in IPA Phase 3. Thus, the differences in infiltration rates may be of less significance in the future. In the case of the funnel factor, the NRC/CNWRA are pursuing a new abstraction that accounts for various mechanisms affecting flow to the waste package. The significance of differences in funnel factors (or equivalent parameters) will be evaluated in future studies. Limited solubility and sorption coefficient data will mean that both the DOE and the NRC/CNWRA may use a high degree of expert judgment in selecting ranges for the parameter values.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA-generated original data contained in this report meets quality assurance requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality for those data. The reader is cautioned that the status of data qualification cited in this report remains to be determined.

ANALYSES AND CODES: No computer codes were used for analyses contained in this report. Therefore, no quality assurance standards for computer code development and use apply to this report. TPA Version 3.1, frequently referred to in the text, is currently under development and will be placed under CNWRA configuration control.

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1 INTRODUCTION

1.1 BACKGROUND

Total system performance assessment (TSPA) is an evaluation process that provides the basis for judging the suitability of a proposed geologic repository for disposal of high-level nuclear waste (HLW). Regulations developed by the Nuclear Regulatory Commission (NRC) based on the U.S. Environmental Protection Agency (EPA) radiation protection standards establish the numerical limits for radionuclide releases, doses, or risks defining safety levels that must be achieved by the proposed repository. The role and purpose of TSPA is to make quantitative estimates of repository performance, taking into account the natural geology and repository induced processes potentially affecting waste isolation. Because of the large variabilities of geologic and experiencing parameters and inherent uncertainties in future system states, the TSPAs conducted by the NRC and the U.S. Department of Energy (DOE) generally use a probabilistic approach.

The NRC and the Center for Nuclear Waste Regulatory Analyses (CNWRA) developed the Total-system Performance Assessment (TPA) code to promote an understanding of the isolation characteristics of the proposed repository and to conduct probing reviews of the DOE TSPAs. The initial version of the TPA code, which was applied in the NRC/CNWRA Iterative Performance Assessment (IPA) Phase 2 (Nuclear Regulatory Commission, 1995), is documented in Sagar and Janetzke (1993). The TPA code consists of an executive module and a set of consequence modules that simulate the long-term isolation performance of the proposed repository taking into account uncertainties in model parameters, conceptual models, and future system states. The simulation process, which integrates a broad spectrum of site-specific data and information (e.g., site characterization data, engineered barrier designs, and biosphere data), produces probabilistic estimates of a set of repository performance measures (e.g., dose, release rate, cumulative release, containment time)

A newer version of the TPA code (Version 3.1)[1] [see Manteufel et al. (1997) for Version 3.0 documentation] was developed to be used in the NRC/CNWRA sensitivity studies and in the review of the DOE TSPA Viability Assessment (VA). The TPA Version 3.1 code incorporates several new conceptual models and more recent site data. The TPA Version 3.1 code accommodates updated aspects of the repository program such as (i) the latest DOE repository layout, waste package (WP), and emplacement designs, (ii) previous, current, and anticipated performance standards (release-based and dose-based), and (iii) variable compliance period (thousands to hundreds of thousands of years).

The basic purpose of this report is to document the TPA input parameter values proposed as the reference values for the IPA Phase 3 study and to compare it with the parameter values used by the DOE in the Repository Integration Program (RIP) (Golder Associates, Inc., 1994) computer code while conducting its TSPA-95 (TRW Environmental Safety Systems, Inc., 1995) study. The DOE is likely to update the TSPA-95 data set for use in TSPA-VA. A comparison of TSPA-VA parameter values and the NRC/CNWRA reference or base case values will be the first step in the review of TSPA-VA. In this report the NRC/CNWRA reference values are composed to those used by the DOE in its TSPA-95. It is recognized this comparison represents a snapshot in time and that selected parameter values are likely to change prior to the conduct of the next NRC and DOE TSPA iteration. In addition, there are, in

[1]Updated documentation for Version 3.1 is in preparation.

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certain cases, differences where distinct modeling approaches make it difficult to directly compare input parameters.

1.2 REPORT CONTENT

Evaluation of the TSPA-VA and the license application (LA) will be a significant part of the NRC review. This will include a critical review of the model abstractions and data used for release and transport of contaminants at the proposed Yucca Mountain (YM) repository. Early identification and analysis of items that significantly affect the estimated repository performance are important to the effective and timely review of the license application. As part of this identification process, sensitivity analyses are being conducted to define controlling model abstractions and parameters. While in some places the DOE TSPA and NRC TPA use different abstractions and parameter values, direct comparison of the two sets of input parameter values is a preliminary step in these sensitivity analyses.

As noted previously, the scope of this report is the comparison of parameter values proposed to be used in IPA Phase 3 and TSPA-95 (TRW Environmental Safety Systems, Inc., 1995). It does not include a detailed comparison of physical process model abstractions except to note where differences in these abstractions limit the direct comparison of parameter values. Objectives of this report include:

- Present, in a succinct manner, input parameter values used in DOE TSPA-95 and proposed for use in IPA Phase 3
- Make initial comparisons to identify differences in the two sets of input parameter values, and
- Highlight significant differences to allow for planning and conducting appropriate sensitivity analyses as part of the NRC/CNWRA technical program.

This report presents the parameter values in tabular format accompanied by discussion of the assumptions used and comparison of significant differences. The organization for the parameter presentation follows that of the TPA Version 3.1 code Module Description and User's Manual (see Manteufel et al., 1997 for Version 3.0)[1], (i.e., reference parameter values will be presented for each of the TPA Version 3.1 code consequence modules and listed with corresponding information from TSPA-95). When available, references for the source of reference values for TPA Version 3.1 are included. References for many of the TSPA-95 model parameters are not included because these were difficult to identify from the available TSPA-95 document. TRW Environmental Safety Systems, Inc. (1995) should be consulted for references on TSPA-95.

Parameters used to describe the physical layout of the repository which are used throughout the TPA Version 3.1 code (referred to as global parameters) such as repository elevation and radionuclide inventory will be presented first, followed by module-specific parameters (e.g., van Genuchten parameters for a particular geostratigraphic unit, volcanic eruption power, or critical relative humidity for initiation of aqueous corrosion of a WP).

2 MODEL DESCRIPTIONS AND OVERVIEW

2.1 TOTAL-SYSTEM PERFORMANCE ASSESSMENT CODE

The TSPA relies on computer simulations that link mathematical models of the important features, events, and processes (FEP) for computing overall system performance. Because of the uncertainty in many of the input parameters, the code is run repeatedly with different assumptions and parameter values to estimate the range of possible model outputs for expected ranges of processes and parameter uncertainty. There are five main categories of data and models contained in the TPA Version 3.1 code:

- System characterization
- Mathematical models for FEPs internal to the system
- Mathematical models for external FEPs
- Models for subsystem performance measures (intermediate results)
- Data and conceptual models for linking modules (coupling parameters and models)

For analysis purposes, models have been segmented into either internal processes (also called base-case processes) or external disruptive processes. The primary distinction is the source that causes a response in the system. If the source is within the system boundary such as the emplaced HLW, then the processes are internal. Sources outside the system boundary are classified as external or disruptive. An example of an internal process is the thermal-hydrologic response caused by the emplacement of heat-dissipating waste. An example of the external process is the seismic activity caused by regional tectonic and geologic processes not related to the repository.

The base-case system is composed of several subsystem models

- Groundwater flow from the ground surface to the proposed repository
- Near-field thermo-hydrologic-mechanical-chemical environment of the engineered barrier system (EBS)
- Corrosion and other anticipated failure mechanisms of the EBS containment
- Release of radionuclides from the EBS into the geologic setting
- Groundwater flow and radionuclide transport (RT) in the unsaturated zone below the proposed repository and into the saturated zone
- Groundwater flow and RT in the saturated zone below the proposed repository to a compliance point (CP) or boundary
- Transport of radionuclides in the biosphere through the groundwater pathway that leads to dose to humans

The disruptive models include

- Climate change
- Faulting
- Seismicity
- Volcanism

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Climate change, while an external FEP, has been treated as an internal event in TPA Version 3.1. Figure 2-1 illustrates the method whereby the EXEC module controls the flow of data to and from the consequence modules and the order consequence modules are called. Faulting, seismicity, volcanism, and climate change can lead to earlier failures of the EBS containment than would otherwise occur. In the case of volcanism, radionuclides also may be released directly into the biosphere through extrusive events that dissipate contaminated volcanic ash to the ground surface.

2.2 TOTAL SYSTEM PERFORMANCE ASSESSMENT—95

TSPA-95 is the third IPA conducted by the DOE on YM. The TSPA-95 report (TRW, Environmental Safety Systems, Inc., 1995) presented the DOE PA approach, assumptions, data, and principal findings of the evaluation. Overall system performance was quantified in TSPA-95 in terms of cumulative release and dose. Compared to TSPA-93 (Wilson et al., 1994), TSPA-95 incorporated additional site data, the then current WP designs and WP emplacement options, and new model abstractions for processes affecting repository performance. Similar to the base of the TPA Version 3.1 code, TSPA-95 modeled performance of the repository using the following internal FEPs: unsaturated zone hydrology, near-field environment, WP degradation, radionuclide release, unsaturated zone transport, saturated zone transport, and dose assessment. TSPA-95 did not consider disruptive scenarios (e.g., volcanism, faulting, seismicity).

To identify significant differences between the NRC/CNWRA approaches to a PA and those presented in TSPA-95 and begin resolving those differences, the NRC/CNWRA have conducted an audit review (Baca and Brient, 1996) and detailed review (Baca and Jarzemba, 1997) of TSPA-95. These reviews examined selected topics of TSPA-95 and provided early feedback to the DOE regarding appropriateness of assumptions and modeling of selected aspects of the repository. The issues these reviews covered include subsystem abstractions, igneous activity, unsaturated and saturated flow, thermal effects on flow, container life and source term, seismicity, near-field environment, RT, and repository design and thermal-mechanical effects.

2.3 REPOSITORY INTEGRATION PROGRAM CODE

The total system performance of the YM repository was calculated in TSPA-95 using the computer program RIP (Golder Associates, Inc., 1993) in conjunction with detailed process-level models. It is composed of four component modules: (i) a WP behavior and radionuclide release module, (ii) a RT pathways module, (iii) a disruptive events module, and (iv) a biosphere dose/risk module. The first module computes the rate at which radionuclides are exposed and transferred out of the WP based on a description of the WP and the near-field environment. The second module uses a phenomenological approach based on a network of user defined pathways. These pathways represent large-scale heterogeneity of the hydrologic system and are subdivided into flow modes. The flow modes vary from one another based on the flow velocity and retardation coefficient. A Markov process algorithm for transport between different flow modes is used to compute a breakthrough curve for the release of radionuclides to the geosphere. The third module computes the effects of disruptive events such as volcanism, faulting, and human intrusion on the performance of the repository which was not used in TSPA-95. The fourth module calculates the dose to a user defined receptor based on the release rate of radionuclides into the geosphere.

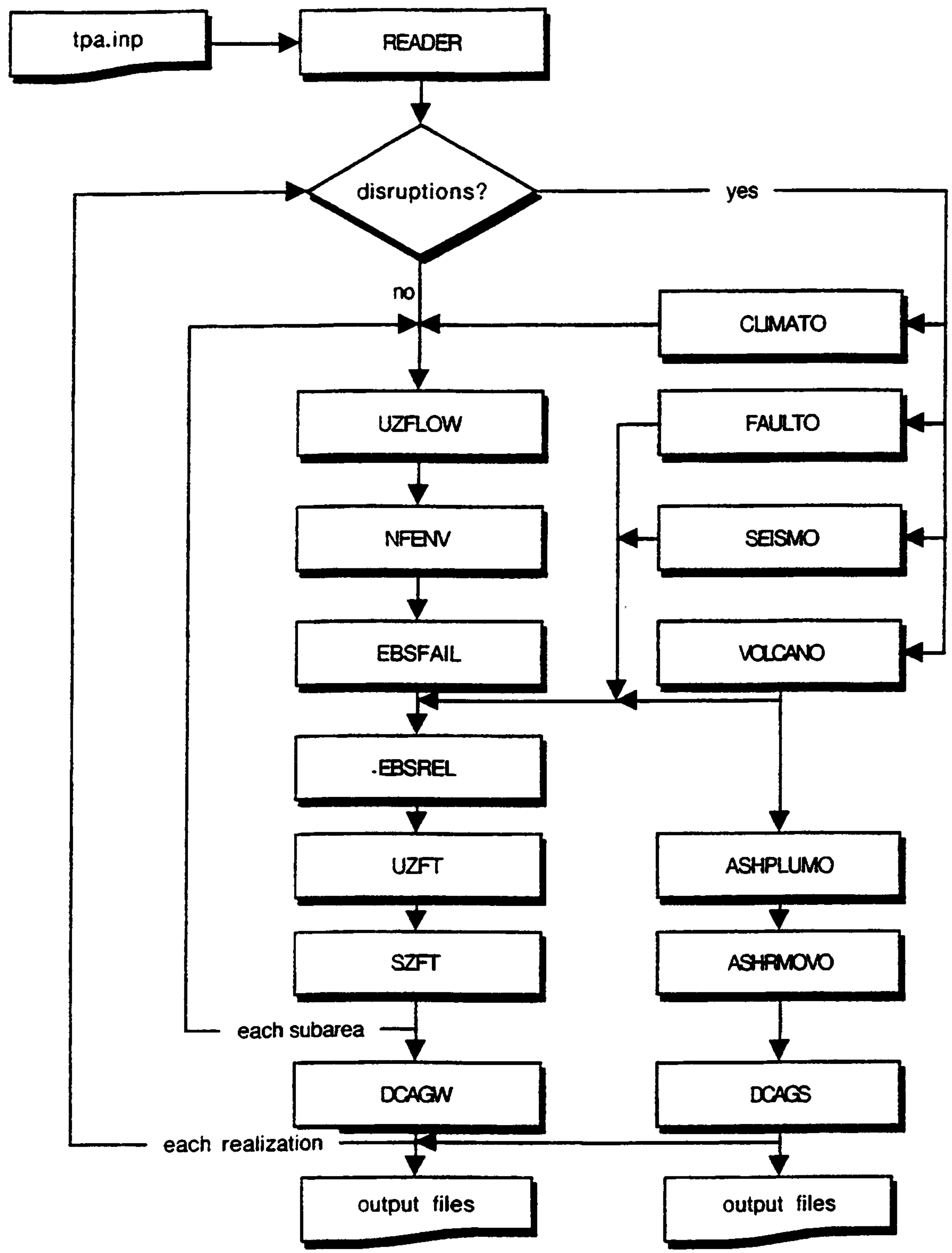

Figure 2-1. Flow diagram for TPA Version 3.1 code

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3 GLOBAL PARAMETERS

This section lists the parameters used to describe the physical layout of the repository, WPs, and waste which are common to several consequences in the TPA Version 3.1 code. Types of parameters included in this global parameter section are

- Repository size, shape, location, drift design, and WP emplacement design
- Waste radionuclide initial inventory
- WP design including WP size, shape, and construction information

3.1 REPOSITORY INFORMATION

This section compares the values used to determine location of the repository and parameters for emplacement of waste inside the repository. The location is set by coordinates in all three dimensions. The parameters for emplacement include the diameter of the drift, the areal mass loading (AML) of the waste, and the spacing between the WPs inside the repository.

The parameter values used to describe the location and loading of the repository are very similar for the two codes. Although the elevations are described from different references points, in both cases the repository is located about 330 m below the ground surface. The only difference between the two codes is that TSPA-95 considered AMLs of both 25.0 metric tons of uranium (MTU)/acre and 83.0 MTU/acre, whereas the base case for the IPA Phase 3 study is proposed to consider only the 83.0 MTU/acre case, although other values may be used in the sensitivity analysis. See table 3-1 for a comparison of the input values used in TSPA-95 and proposed to be used as the IPA Phase 3 parameter values.

3.2 WASTE PACKAGE INFORMATION

This section compares the parameter values used to describe the size and shape of the WP. The containers consist of two layers of steel. The outer layer is carbon steel, while the inner layer is corrosion-resistant stainless steel. The values for the description of the WP include the outer length and diameter of the WP, the thickness of the walls of the WP, the internal diameter and length of the WP, and the amount of waste stored in one WP.

The largest difference between the input parameters is that TSPA-95 used values for the spent fuel (SF) and the Defense High Level Waste (DHLW) whereas the reference values proposed for IPA Phase 3 are for only SF. The proposed IPA Phase 3 reference parameter value for WP payload is 10 percent smaller than in TSPA-95, with values of 8.8 MTU/package and 9.74 MTU/package respectively (see table 3-2). The reason for this difference is that TSPA-95 used only pressurized water reactor (PWR) SF for their value, whereas the proposed IPA Phase 3 reference parameter values are for a mixture of boiling water reactor (BWR) and PWR fuel.

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Table 3-1. Comparison of the reference parameter values used by TSPA-95 and proposed to be used in IPA Phase 3 to describe the repository

Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	**Value**	**Distribution**	**Value**	**Source**
Elevation of repository horizon above sea level (m)	constant	1074	constant	1072	CRWMS (1996)
Elevation of ground surface above sea level (m)	constant	1414	constant	1400	CRWMS (1996)
Coordinates of NE corner of repository [m in Universal Transverse Mercator Coordinate System (UTMCS)]	constants	x = 548600.0 y = 4079040.0	constants	x = 548600.0 y = 4079040.0	CRWMS M&O (1994b)
Coordinates of NW corner of repository (m in UTMCS)	constants	x = 547400.0 y = 4079040.0	constants	x = 547400.0 y = 4079040.0	CRWMS M&O (1994b)
Coordinates of SE corner of repository (m in UTMCS)	constants	x = 548600.0 y = 4076200.0	constants	x = 548600.0 y = 4076200.0	CRWMS M&O (1994b)
Coordinates of SW corner of repository (m in UTMCS)	constants	x = 547400.0 y = 4076200.0	constants	x = 547400.0 y = 4076200.0	CRWMS M&O (1994b)
Emplacement drift diameter (m)	constant	5	constant	5	CRWMS (1996)
AML (MTU/acre)	constants	25.0 (low) 83.0 (high)	constant	83.0	CRWMS M&O (1994b)
WP spacing (m)	constants	19 for high areal loading 32 for low areal loading	constant	19	TRW, Environmental Safety Systems, Inc. (1995)

Table 3-2. Comparison of the reference parameter values used by TSPA-95 and proposed to be used in IPA Phase 3 to describe the waste package

Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
Internal diameter of waste package (m)	constant	SF = 1.56 DHLW = 1.57	constant	1.56	Doering (1995)
Internal length of WP (m)	constant	SF = 4.93 DHLW = 3.04	constant	4.93	Doering (1995)
WP payload (MTU/package)	constant	SF = 9.74 DHLW = 1.828	constant	8.8	Manteufel (1997)
Length of WP (m)	constant	SF = 5.68 DHLW = 3.68	constant	5.68	Doering (1995)
Diameter of WP (m)	constant	SF = 1.80 DHLW = 1.71	constant	1.80	Doering (1995)
Thickness of the outer overpack (m)	constant	SF = 0.1 DHLW = 0.1	constant	0.1	Doering (1995)
Thickness of the inner overpack (m)	constant	SF = 0.02 DHLW = 0.02	constant	0.02	Doering (1995)

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3.3 CONTAMINANT INFORMATION

The input values that describe the waste itself include the total amount of waste disposed, the average burnup of the waste, the physical properties of the waste, and the initial inventories of all radionuclides. Except for the initial inventories, the input parameters for the two studies have no significant differences between them and can be found in table 3-3. The initial inventories of radionuclides in the waste used in the two assessments are shown in table 3-4. The TSPA-95 values were calculated by dividing the Ci/package value given in TSPA-95 by the number of MTU/package. The TSPA-1995 inventories are based on 35 percent BWR, and 65 percent PWR fuel, while the inventories proposed to be used as reference values in IPA Phase 3 are based on 40 percent BWR, and 60 percent PWR fuel, which could account for some of the differences in initial inventory.

The initial inventories of five radionuclides have a significant (greater than a factor of two) difference among them. Pa-231 has a listed initial inventory of 3.30e04 Ci/package in TSPA-1995, or 3.39e3 Ci/MTU, compared to the proposed IPA Phase 3 reference value of 1.95e−5 Ci/MTU. This difference is likely due to a typographical error in TSPA-1995 because if the value in the table is changed to 3.30e−4 Ci/package from 3.30e04 Ci/package, the value of 3.39e−5 Ci/MTU matches well with the proposed IPA Phase 3 reference value. The other four radionuclides, Am-242m, CM-244, Cm-245, and Cm-246 all have initial inventories between 2 and 3 times larger in TSPA-95 than in the TPA Version 3.1 code.

Table 3-3. Comparison of the reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 to describe the properties of the high-level nuclear waste

Contaminant Input Values					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Total amount of waste (MTU)	constant	SF = 63000 DHLW = 7000	constant	70000	CRWMS (1996)
Burnup of waste (GWd/MTU)	constant	SF = 36.666 DHLW = 10.0	—	—	—
Spent fuel molecular weight (g/mol)	constant	250	constant	250	Mohanty et al. (1996) (Based on UO_2)
Spent fuel density (kg/m^3)	—	—	constant	10,600	Mohanty et al. (1996) (Based on UO_2)

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Table 3-4. Comparison of the initial inventories of high-level nuclear waste used by TSPA-95 and proposed to be used as the reference values in IPA Phase 3

Initial Radionuclide Inventory — Spent Fuel					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (Ci/MTU) (at 30 yr)	Distribution	Value (Ci/MTU) (at 30 yr)	Source
Ac-227	constant	1.84e−5	constant	1.38e−5	Manteufel et al. (1997); Lozano et al. (1994)
Ag-108m	—	—	constant	1.07e−2	Manteufel et al. (1997); Lozano et al. (1994)
Am-241	constant	3.83e3	constant	3.09e3	Manteufel et al. (1997); Lozano et al. (1994)
Am-242m	constant	2.22e1	constant	6.83e0	Manteufel et al. (1997); Lozano et al. (1994)
Am-243	constant	2.55e1	constant	1.54e1	Manteufel et al. (1997); Lozano et al. (1994)
C-14	constant	1.42e0	constant	1.33e0	Manteufel et al. (1997); Lozano et al. (1994)
Cl-36	constant	1.14e−2	constant	1.17e−2	Manteufel et al. (1997); Lozano et al. (1994)
Cm-243	—	—	constant	9.40e0	Manteufel et al. (1997); Lozano et al. (1994)
Cm-244	constant	1.19e3	constant	5.34e2	Manteufel et al. (1997); Lozano et al. (1994)
Cm-245	constant	3.45e−1	constant	1.25e−1	Manteufel et al. (1997); Lozano et al. (1994)
Cm-246	constant	7.14e−2	constant	2.55e−2	Manteufel et al. (1997); Lozano et al. (1994)

Table 3-4. Comparison of the initial inventories of high-level nuclear waste used by TSPA-95 and proposed to be used as the reference values in IPA Phase 3

Initial Radionuclide Inventory — Spent Fuel					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (Ci/MTU) (at 30 yr)	Distribution	Value (Ci/MTU) (at 30 yr)	Source
Cs-135	constant	5.27e−1	constant	3.51e−1	Manteufel et al. (1997); Lozano et al. (1994)
Cs-137	—	—	constant	4.81e4	Manteufel et al. (1997); Lozano et al. (1994)
I-129	constant	3.52e−2	constant	2.95e−2	Manteufel et al. (1997); Lozano et al. (1994)
Mo-93	—	—	constant	1.01e−2	Manteufel et al. (1997); Lozano et al. (1994)
Nb-93m	constant	1.87e0	—	—	—
Nb-94	constant	8.45e−1	constant	5.03e−1	Manteufel et al. (1997); Lozano et al. (1994)
Ni-59	constant	2.42e0	constant	2.46e0	Manteufel et al. (1997); Lozano et al. (1994)
Ni-63	constant	3.18e2	constant	2.62e2	Manteufel et al. (1997); Lozano et al. (1994)
Np-237	constant	4.47e−1	constant	3.03e−1	Manteufel et al. (1997); Lozano et al. (1994)
Pa-231	constant	3.38e3	constant	2.66e−5	Manteufel et al. (1997); Lozano et al. (1994)
Pb-210	constant	6.93e−7	constant	6.40e−7	Manteufel et al. (1997); Lozano et al. (1994)

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Table 3-4. Comparison of the initial inventories of high-level nuclear waste used by TSPA-95 and proposed to be used as the reference values in IPA Phase 3

Initial Radionuclide Inventory — Spent Fuel					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (Ci/MTU) (at 30 yr)	Distribution	Value (Ci/MTU) (at 30 yr)	Source
Pd-107	constant	1.30e−1	constant	1.05e−1	Manteufel et al. (1997); Lozano et al. (1994)
Pu-238	constant	3.13e3	constant	1.80e3	Manteufel et al. (1997); Lozano et al. (1994)
Pu-239	constant	3.66e2	constant	3.08e2	Manteufel et al. (1997); Lozano et al. (1994)
Pu-240	constant	5.40e2	constant	5.08e2	Manteufel et al. (1997); Lozano et al. (1994)
Pu-241	constant	3.48e4	constant	2.84e4	Manteufel et al. (1997); Lozano et al. (1994)
Pu-242	constant	2.07e0	constant	1.60e0	Manteufel et al. (1997); Lozano et al. (1994)
Ra-226	constant	2.57e−6	constant	2.38e−6	Manteufel et al. (1997); Lozano et al. (1994)
Ra-228	constant	3.18e−10	—	—	—
Se-79	constant	4.53e−1	constant	3.80e−1	Manteufel et al. (1997); Lozano et al. (1994)
Sm-151	constant	3.63e2	constant	2.72e2	Manteufel et al. (1997); Lozano et al. (1994)
Sn-121m	—	—	constant	6.03e−1	Manteufel et al. (1997); Lozano et al. (1994)

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Table 3-4. Comparison of the initial inventories of high-level nuclear waste used by TSPA-95 and proposed to be used as the reference values in IPA Phase 3

Initial Radionuclide Inventory — Spent Fuel					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (Ci/MTU) (at 30 yr)	Distribution	Value (Ci/MTU) (at 30 yr)	Source
Sn-126	constant	8.73e−1	constant	7.15e−1	Manteufel et al. (1997); Lozano et al. (1994)
Sr-90	—	—	constant	3.30e4	Manteufel et al. (1997); Lozano et al. (1994)
Tc-99	constant	1.43e1	constant	1.23e1	Manteufel et al. (1997); Lozano et al. (1994)
Th-229	constant	3.64e−7	constant	2.08e−7	Manteufel et al. (1997); Lozano et al. (1994)
Th-230	constant	3.69e−4	constant	3.42e−4	Manteufel et al. (1997); Lozano et al. (1994)
Th-232	constant	4.47e−10	—	—	—
U-232	—	—	constant	2.04e−2	Manteufel et al. (1997); Lozano et al. (1994)
U-233	constant	7.20e−5	constant	4.97e−5	Manteufel et al. (1997); Lozano et al. (1994)
U-234	constant	1.38e0	constant	1.24e0	Manteufel et al. (1997); Lozano et al. (1994)
U-235	constant	1.73e−2	constant	1.69e−2	Manteufel et al. (1997); Lozano et al. (1994)
U-236	constant	2.79e−1	constant	2.40e−1	Manteufel et al. (1997); Lozano et al. (1994)

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Table 3-4. Comparison of the initial inventories of high-level nuclear waste used by TSPA-95 and proposed to be used as the reference values in IPA Phase 3

Initial Radionuclide Inventory — Spent Fuel					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (Ci/MTU) (at 30 yr)	Distribution	Value (Ci/MTU) (at 30 yr)	Source
U-238	constant	3.15e−1	constant	3.19e−1	Manteufel et al. (1997); Lozano et al. (1994)
Zr-93	constant	2.45e0	constant	1.85e0	Manteufel et al. (1997); Lozano et al. (1994)

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4 CONSEQUENCE MODULE PARAMETERS

4.1 UNSATURATED ZONE FLOW — UZFLOW MODULE IN TPA VERSION 3.1

4.1.1 Description of the Proposed IPA Phase 3 Model

The unsaturated zone flow module (UZFLOW) calculates time-dependent unsaturated zone percolation flux into each subarea of the repository. UZFLOW uses a time history of mean annual precipitation (MAP) and mean annual temperature (MAT) generated by the CLIMATO module to modify the mean annual infiltration (MAI) occurring under current and postulated future climatic conditions. Assuming that no lateral flow diversion occurs in the subsurface and that the flow field is in steady state, MAI can be equated to areally averaged deep percolation flux. This is a conservative formulation of deep percolation.

Based on elevation, soil depth, soil and bedrock properties, and climatic variables (MAP and MAT), the MAI is estimated using an empirical relationship appropriate to YM (Stothoff et al., 1997). The empirical relationship was derived by analyzing the MAI generated from nearly 200 one-dimensional (1D) bare-soil simulations with various combinations of MAP, MAT, solar aspect, soil depth, soil hydraulic properties, and bedrock soil properties. The empirical relationship is appropriate for shallow bare soil overlying an open fracture in an impermeable bedrock. The empirical relationship assumes that MAI can be parameterized as a function of the input variables (e.g., MAP, MAT, soil depth). A simple perturbation approach is used with a base set of input variables to calculate a base value for MAI with a 1D simulation. Additional simulations were run, perturbing one or more input variables, to build up the response of MAI to the input variables.

4.1.2 Description of the TSPA-95 Model

The conceptual model of unsaturated zone hydrology at YM used in TSPA-95 analyses provides a qualitative description of how water flow is assumed to be distributed within the unsaturated zone. A part of the precipitation at the ground surface enters the unsaturated zone as infiltration flux. This flux is modified to a percolation flux at the proposed repository horizon within the Topopah Springs welded unit. At the repository horizon the average percolation flux is distributed (for each hydrostratigraphic unit) between fracture and matrix flow depending on the hydrologic properties of the unit. Each individual drift has the average percolation flux redistributed across it to determine a local percolation flux that reflects the local spatial variability in material properties. Each local percolation flux is further partitioned into a component entering the drifts via dripping fractures and a component retained by the intact rock matrix surrounding the drift.

4.1.3 Comparison of the Unsaturated Zone Flow Input

The model used in TSPA-95 and the model proposed to be used in IPA Phase 3 use slightly different approaches in determining the infiltration rate into the repository area. TSPA-95 used constant climatic parameters over the entire area of the repository while the model proposed to be used in IPA Phase 3 varies the mean precipitation and temperature depending on the elevation of the surface. For a ground surface elevation of 1,400 m in the proposed IPA Phase 3 model the calculated precipitation of

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175 mm/yr agrees well with the TSPA-95 value of 170 mm/yr. The average infiltration for the initial climate varies considerably between the two studies with the IPA Phase 3 study proposing to use a reference value of 1 to 10 mm/yr averaged over the entire repository area while TSPA-95 used a range of only 0.5 to 2.0 mm/yr for the high-infiltration case. The DOE has indicated that larger infiltration rates that correspond to the range proposed to be used in the IPA Phase 3 study will be used in future TSPAs[2]. This parameter has the potential to have a substantial effect on the performance of the repository. See table 4-1 for a listing of the UZFLOW model parameter values used in TSPA-95 and proposed to be used in IPA Phase 3.

4.2 NEAR FIELD ENVIRONMENT—NFENV MODULE OF TPA VERSION 3.1

4.2.1 Description of the Proposed IPA Phase 3 Model

Based on the infiltration rate of groundwater, the near-field environment module (NFENV) calculates the time-dependent hydrothermal environment of the WP including:

- Average repository-horizon rock temperature
- WP surface and SF temperatures
- Relative humidity at the WP surface
- Flow rate of groundwater onto the WP
- pH and chloride concentration of groundwater flowing onto the WPs

The repository-horizon average rock temperature is computed using an analytic conduction-only model for mountain-scale heat transfer. The model is based on a heated rectangular region residing in a semi-infinite medium. The analytic mountain-scale conduction model predicts the rock-wall temperature as a function of time, which allows calculation of WP temperature. A multimode (i.e., conduction, convection, and radiation) heat transfer model is used for modeling drift-scale heat transfer. Using this model, the WP surface temperature and maximum SF temperature are calculated from the temperature of the rock and the heat output of the WP.

The thermohydrologic conceptual model implemented in NFENV assumes there are both matrix and fracture flow continua. It is also assumed that a condensate zone layer exists at a temperature above the boiling point isotherm. Below the isotherm is a reflux zone. Above the isotherm, liquid is supplied to the fractures at a rate proportional to the thickness of the condensate zone layer. In the reflux zone, liquid from the condensate zone flows down through fractures and is vaporized. The vapor rises to the top of the boiling zone and condenses back to liquid in the condensate zone. The thickness of the reflux zone is dependent on the infiltration flux and the local temperature gradient. When the thickness of the reflux zone is below the elevation of the top of the drift, water begins to drip into the drift. When the temperature drops below boiling, the remainder of the water in the condensate zone quickly flows down into the repository. The pH and chloride concentrations of the groundwater flowing onto the WPs are based on table-lookup using results from the MULTIFLO code (Lichtner and Seth, 1996).

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[2] van Luik, A. 1997. Presentation to ACNW May 21. Las Vegas, Nevada.

Table 4-1. Comparison of the reference parameter values used for the unsaturated zone flow models used in TSPA-95 and proposed to be used in IPA Phase 3

UZFLOW Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
Mean annual precipitation (mm/yr)	constant	170	calculated from ground surface elevation, m	exp(4.26 + 0.000646Z)*	Hevesi et al. (1992)
Mean annual temperature (°C)	NA	NA	calculated from ground surface elevation, m	25.83 − 0.0084Z*	Stothoff et al. (1997); McKinley and Oliver (1994)
Standard deviation of precipitation (mm/yr)	NA	NA	constant	10.0	Assumed based on Stothoff et al. (1997)
Standard deviation of temperature (°C)	NA	NA	constant	1.0	Assumed based on Stothoff et al. (1997)
Correlation between precipitation and temperature perturbations about the means	NA	NA	constant	−0.8	Assumed based on Stothoff et al. (1997)
Areally averaged mean annual infiltration for the initial (current) climate (mm/yr)	uniform	*low infiltration:* Min = 0.01 Max = 0.05 *high infiltration:* Min = 0.5 Max = 2.0	log-uniform	Min = 1 Max = 10	CNWRA* staff best estimate

*Z = Elevation above sea level (m)
*CNWRA = Center for Nuclear Waste Regulatory Analyses

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4.2.2 Description of the TSPA-95 Model

The near-field environment model used in TSPA-95 simulates various processes initiated as a result of the emplacement of heat-generating waste, including conductive and convective heat transfer; boiling and condensation; capillary adsorption and vapor pressure lowering; and thermal buoyancy driven vapor flow. The computer code FEHM (Finite Element Heat and Mass Transfer), developed at Los Alamos National Laboratory (Zyvoloski et al., 1995) was used to calculate near-field environment conditions. FEHM is a multidimensional heat and mass transfer code that simulates nonisothermal multiphase flow in porous media under saturated and unsaturated conditions (Zyvoloski et al., 1995), modified to also account for radiative heat transfer.

The code simulates fluid flow in both gas and liquid phases under pressure, viscous, and gravity forces according to Darcy's equation. FEHM also accounts for the capillarity between liquid and gas phases as well as phase interference (relative permeability) effects. Kelvin's law of vapor pressure lowering was used to calculate relative humidity in the near-field environment. The model assumes a two-dimensional (2D) geometry in a plane orthoganal to the drift extending from the ground surface to the water table. Heat transfer along the drift is accounted for by axial smearing over the WP spacing distance. Fracture-matrix interaction is modeled using the equivalent continuum assumption that results in volume averaging of fracture and matrix characteristic parameters. This forces liquid movement to occur primarily within the matrix and be controlled by matrix permeability.

Groundwater flow rate into a drift is modeled with a dripping flux model that assumes that the percolation flux is log-normally distributed with a mean equal to the infiltration flux. The flux of water dripping into a drift is zero if the matrix saturated conductivity is less than the percolation flux. If the matrix saturated conductivity is greater than the percolation flux, the dripping flux is calculated as the difference between the matrix saturated conductivity and the percolation flux. The total flux contacting a WP is assumed to be the dripping flux multiplied by the area of the WP and by a funnel factor of 4. This funnel factor allows the flux of water onto a WP to come from an area larger than the that of the WP.

4.2.3 Comparison of the Near-Field Environment Input Parameter Values

Parameter values used in TSPA-1995 and proposed to be used in IPA Phase 3 as reference values to calculate the near-field environment conditions are very similar. Many of the values proposed to be used in IPA Phase 3 are based on those used in TSPA-95. TSPA-95 included a smearing length to account for the use of a 2D model to represent the WP inside a drift, while it is proposed that IPA Phase 3 will not. The proposed IPA Phase 3 is expected to consider a reflux zone which holds evaporated water above the repository and eventually drips into the repository, whereas TSPA-95 did not. See table 4-2 for a listing of the values used in TSPA-95 and proposed to be used as reference values in IPA Phase 3.

Table 4-2. Comparison of reference parameter values for the near field environment modules used in TSPA-95 and proposed to be used in IPA Phase 3

NFENV Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
Ambient repository temperature (°C)	constant	20	constant	20	Assumed in TRW Environmental Safety Systems, Inc. (1995)
Average geothermal gradient (°C/km)	constant	20	constant	20	Assumed in TRW Environmental Safety Systems, Inc. (1995)
Mass density of rock (kg/m^3)	constant	2580	constant	2580	U.S. Department of Energy (1990)
Average ground surface temperature (°C)	constant	13	constant	13	Assumed in TRW Environmental Safety Systems, Inc. (1995)
Average water table temperature (°C)	constant	27	constant	27	Assumed in TRW Environmental Safety Systems, Inc. (1995)
Specific heat of rock (J/kg-K)	constant	840	constant	840	U.S. Department of Energy (1990)
Thermal conductivity of rock (W/m-K)	constant	2.10	uniform	Min = 1.8 Max = 2.2	U.S. Department of Energy (1993)
Emissivity of drift wall	—	—	constant	0.8	Incropera & Dewitt (1992)
Emissivity of WP	—	—	constant	0.7	Incropera & Dewitt (1992)
Thermal conductivity of floor (W/m-°C)	—	—	constant	0.6	Incropera & Dewitt (1992)
Thermal conductivity of stagnant air (W/m-°C)	—	—	constant	0.03	Incropera & Dewitt (1992)
Effective thermal conductivity of unbackfilled drift (W/m-°C)	—	—	constant	0.9	Manteufel (1997)
Time backfill emplaced (yr)	constant	100	constant	100	CRWMS (1996)

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Table 4-2. Comparison of reference parameter values for the near field environment modules used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

NFENV Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Effective thermal conductivity of backfill (W/m-°C)	constant	0.6	constant	0.6	U.S. Department of Energy (1990)
Initial heat output of waste (Kw/MTU)	constant	0.98	—	—	—
Thermal conductivity of inner stainless steel container wall (W/m-°C)	—	—	constant	15	Incropera & DeWitt (1992)
Thermal conductivity of outer carbon steel wall (W/m-°C)	—	—	constant	50	Incropera & DeWitt (1992)
Thermal conductivity of basket and SF (W/m-°C)	—	—	constant	1	Assumed based on Manteufel and Todreas (1994)
Boiling point of water (°C)	constant	100	constant	97	Manteufel (1997)
Smearing length (m)	constant	15 for 83 MTU/acre; 30 for 25 MTU/acre	—	—	—
Length of reflux zone (m)	—	—	constant	20	CNWRA staff best estimate
Maximum flux in reflux zone (m/s)	—	—	constant	1e−9	CNWRA staff best estimate
Perched bucket volume per subarea (m^3/m^2)	—	—	constant	0.5	CNWRA staff best estimate

4.3 ENGINEERED BARRIER SYSTEM FAILURE—EBSFAIL MODULE OF TPA VERSION 3.1

4.3.1 Description of the Proposed IPA Phase 3 Model

Based on the temperature and relative humidity of the near-field environment and chemical composition of fluid contacting the WP, the EBS failure module (EBSFAIL) calculates the failure time of the EBS due to various modes of degradation: dry oxidation, uniform aqueous corrosion, localized (pitting and crevice) corrosion, and fracture failure. There are three types of failure considered by EBSFAIL: initial failure (Type 1), disruptive event failure (Type 2), and mechanical failure (Type 3). It is assumed that corrosion or mechanical failure affects all WPs equally in a cell so that when one WP fails, then all WPs in that cell that have not already failed owing to Type 1 or 2 failures also fail simultaneously. Failure can also occur by brittle fracture due to mechanically dominated Type 3 processes. No allowance is given to the protection ability of the multipurpose container or the fuel cladding against corrosion or mechanical failure. After the outer and inner overpacks are penetrated or failed by fracture, the SF is considered to be completely exposed to the near-field environment.

Water condensation is assumed to begin when the temperature of the WP surface decreases to a value where the relative humidity of the environment surrounding the WP reaches a threshold or critical relative humidity for humid air corrosion. A second critical relative humidity will lead to aqueous corrosion. The thickness of the condensed liquid layer is assumed to be the same regardless of the presence or absence of backfill material around the WP. The environment surrounding the WP is treated as dry air if the relative humidity is lower than the threshold relative humidity. An amount of outer overpack material consumed by dry oxidation is calculated to determine penetration of the oxidation front. If at any time step water condensation takes place, the calculation of oxidation in dry air is interrupted and aqueous corrosion calculation begins.

Dry oxidation can be either uniform, which tends to form a layer that protects the package against further oxidation, or localized, which may adversely affect the long-term container integrity in a dry-air environment. Localized dry oxidation takes place by mass transport through short-circuit diffusion paths, such as interfaces between metal and oxide (or other inclusions and precipitates) or grain boundaries. For the calculations of intergranular oxide formation, a mathematical model developed by Oishi and Ichimura (1979) is used, in which oxygen diffusion in the matrix and along the grain boundary in an infinite 1D body is calculated simultaneously. The main assumptions in the calculations are negligible effects of external oxide, diffusion of oxygen into metallic phases along grain boundaries, and diffusion of oxygen into metallic matrices.

Aqueous corrosion takes place only when the metal surface is covered by a water film. The critical relative humidity above which atmospheric corrosion of most metals occurs closely coincides with the relative humidity necessary for formation of multiple water monolayers where the liquid film behaves in a manner similar to bulk water. Under these conditions, corrosion is governed by the same electrochemical laws applicable to corrosion of metals immersed in an aqueous electrolyte. The EBSFAIL corrosion models calculate the rates of uniform wet corrosion and localized corrosion following the approach adopted previously in the Substantially Complete Containment-Example Analysis of a Referenced Container code (SCCEX) (Cragnolino et al., 1994). The dominant corrosion process at any given time is dictated by the corrosion potential and the appropriate critical potential for that process. The corrosion potential is the mixed potential established at the metal/solution interface when a metal is immersed in a given environment. Corrosion potentials are calculated on the basis of kinetic expression

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for the cathodic reductions of oxygen and water and the passive current density for the anodic oxidation of the metals.

If the corrosion potential exceeds the critical potential for pit initiation, pits are assumed to initiate and grow without an initiation time. If the corrosion potential falls below the repassivation potential, previously growing pits are assumed to cease growing and the material passivates, corroding uniformly at a low rate through a passive film. Following penetration of the outer container, electrical contact of the inner and outer container through the presence of an electrolyte path promotes galvanic coupling. The galvanic coupling model evaluates whether penetration of the inner container by localized corrosion is possible; if not, uniform corrosion or mechanical fracture becomes the predominant failure mechanism because the inner container is protected against localized corrosion.

Mechanical failure of the WP in the EBSFAIL module is considered the result of fracture of the outer steel overpack. In each time interval, a mechanical failure test is conducted for the new thickness resulting from metal oxidation to evaluate if failure due to mechanical fracture occurs. As a first approximation, other mechanical failure processes such as buckling or yielding are not considered plausible for the current design of the WP due to the relatively large thickness of the container wall. It should be noted that active uniform corrosion of the carbon steel overpack is not expected under the passivating conditions prevailing in the near-field environment and, therefore, failure modes such as buckling or yielding that would require significant generalized thinning of the container wall in the presence of external loads, were not included in the analysis. A simple fracture model is used in EBSFAIL, based on a generalized expression for the stress intensity factor developed by linear-elastic fracture mechanics.

4.3.2 Description of the TSPA-95 Model

WP degradation modes evaluated in TSPA-95 include pitting corrosion and humid air and aqueous corrosion. The degradation rate of the WP was determined by empirical formulas that determined corrosion rate based on the following factors: materials used in the WP fabrication; the thickness of the WP walls; thermal load in the repository; possible presence of backfill; size of the emplacement drifts; near-field temperature, relative humidity, and sulfur-dioxide content of the air; criteria for corrosion initiation; and rate of corrosion as a function of near-field thermohydrologic environment. A detailed stochastic WP performance simulation model was developed for TSPA-95. The stochastic simulation model incorporated the following five individual corrosion models: (i) humid-air general corrosion model for the outer barrier, (ii) stochastic humid-air pitting corrosion model for the outer barrier, (iii) aqueous general corrosion model for the outer barrier, (iv) stochastic aqueous pitting corrosion model for the outer barrier, and (v) aqueous pitting corrosion model for the inner barrier.

TSPA-95 divided the waste container overpacks into a corrosion allowance material (carbon steel) and a corrosion resistant material (stainless steel). The humid-air general corrosion model for the corrosion allowance material was developed as an empirical function from corrosion data correlated to exposure time, relative humidity, temperature, and sulfur-dioxide content in air. Aqueous corrosion was modeled in a similar manner with empirical equations based on data with corrections for temperature dependence of corrosion rates. These empirical relationships were obtained by a reduction of experimental corrosion data to account for the temperature and relative humidity under which the data were collected. This resulted in corrosion relationships that were nominally appropriate for the quasi-steady-state conditions (compared to those under which the corrosion data were collected) expected in the repository.

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Fitting parameters (b_0, b_1, b_2, b_3) for use in these equations were taken from Larrabee (1953), Coburn (1978), Southwell (1970), Mercer et al. (1968), and Brasher and Mercer (1968).

Pitting corrosion of the corrosion allowance material is modeled using a pitting factor defined as the ratio of the maximum pit depth to the general corrosion depth at a given time. This pitting factor is sampled randomly from a distribution with a mean of 4 and a standard deviation of 1 and is used as a multiplier to the general corrosion depth.

Pitting corrosion under aqueous conditions was assumed to be the only significant active corrosion mode for the corrosion resistant material (i.e., no significant humid air or general aqueous corrosion of the corrosion resistant material occurred). Expert elicitation data that provide a range of time-independent pit growth rates in aqueous conditions at 70 and 100 °C were used to model pit corrosion of the corrosion resistant material. For the pit-growth-rate ranges at other temperatures, these values were extrapolated as a function of temperature in an Arrhenius-type functional form. In TSPA-95, cladding performance as a barrier to radionuclide release after failure of the waste disposal container was evaluated using approaches similar to those in the additional sensitivity study to TSPA-93 (CRWMS, 1994).

4.3.3 Comparison of the Engineered Barrier System Failure Input Parameter Values

The conceptual model proposed for IPA Phase 3 to calculate the failure time of the WP are considerably different from the methods used in TSPA-95. TSPA-95 used an empirical model to calculate the rate of corrosion based on fitting a formula to experimental corrosion data. The proposed IPA Phase 3 model employs a mechanistic model to calculate rate of corrosion of the WP based on formulas that describe the physical processes that are occurring as the corrosion takes place. Other differences in the two approaches to calculating the failure times of the WP include the types of corrosion which are considered in the model. Unlike the proposed IPA Phase 3 model, TSPA-95 does not consider dry air corrosion. In TSPA-95, simulations were conducted to evaluate the effect of WP cathodic protection by assuming that pitting corrosion of the corrosion resistant inner barrier would be delayed until the thickness of the carbon steel outer barrier was reduced by 75 percent. The proposed IPA Phase 3 model uses a galvanic coupling efficiency term can be varied between 0 and 1, but is currently thought to be close to 0 or 1. Because of the large differences in the two approaches, there are few common input parameters for this part of the PA so it is difficult to make meaningful comparisons in the data sets.

In TSPA-95, the thickness of the water film on the WP surface was a constant with a value of 0.001 m, while the proposed IPA Phase 3 reference value is 0.002 m. The proposed IPA Phase 3 reference value for the critical relative humidity at which humid-air corrosion will initiate is a range from 0.55 to 0.65, while in TSPA-95 the range is from 0.65 to 0.75. The critical relative humidity at which aqueous corrosion will initiate is proposed to be a uniform range of 0.75 to 0.85 as the reference values in IPA Phase 3, whereas in TSPA-95 it was a uniform range of 0.85 to 0.95. See table 4-3 for a listing of the values used in TSPA-95 and proposed to be used as reference values in IPA Phase 3.

Table 4-3. Listing of reference parameter values for the engineered barrier system failure module used in and proposed to be used in IPA Phase 3

EBSFAIL Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Average radius of the metal grains constituting the WP outer overpack (μm)	—	—	constant	5	Assumed in Mohanty et al. (1996)
Thickness of grain boundary used in the model for calculating coupled oxygen diffusion along grain boundaries in metal (μm)	—	—	constant	7e−4	Assumed in Mohanty et al. (1996)
Constant relating matrix and grain boundary oxygen diffusivities in metal	—	—	constant	1.0e−2	Assumed in Mohanty et al. (1996)
Critical relative humidity above which humid-air corrosion may initiate	uniform	Min = 0.65 Max = 0.75	uniform	Min = 0.55 Max = 0.65	CNWRA staff best estimate
Critical relative humidity above which aqueous corrosion may initiate	uniform	Min = 0.85 Max = 0.95	uniform	Min = 0.75 Max = 0.85	CNWRA staff best estimate
Thickness of water film on WP surface (m)	constant	1.0e−3	constant	2.0e−3	Assumed in Mohanty et al. (1996)
Transfer coefficient for oxygen reduction reaction for WP outer overpack	—	—	uniform	Min = 0.500 Max = 1.000	Assumed based on Calvo and Schiffrin (1988)
Transfer coefficient for water reduction reaction for WP outer overpack	—	—	uniform	Min = 0.250 Max = 0.500	Bockris and Reddy (1970)
Transfer coefficient for oxygen reduction reaction for WP inner overpack	—	—	uniform	Min = 0.500 Max = 1.000	Assumed based on Calvo and Schiffrin (1988)
Transfer coefficient for water reduction reaction for the WP inner overpack	—	—	uniform	Min = 0.25 Max = 0.75	Assumed based on Bockris and Reddy (1970)

Table 4-3. Listing of reference parameter values for the engineered barrier system failure module used in and proposed to be used in IPA Phase 3 (cont'd)

EBSFAIL Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
Rate constant for oxygen reduction for the WP outer overpack (C-m/yr/mol)	—	—	uniform	Min = 3.800e9 Max= 3.800e12	Assumed based on Bockris and Reddy (1970); Calvo (1979)
Rate constant for water reduction for the WP outer overpack ($C/m^2/yr$)	—	—	uniform	Min = 1.600e−4 Max = 1.600e2	Assumed based on Turnbull and Gardner (1982)
Activation energy for oxygen reduction reaction for WP outer overpack (J/mol)	—	—	uniform	Min = 3.000e4 Max = 5.000e4	Assumed based on Calvo (1979)
Activation energy for water reduction reaction for WP outer overpack (J/mol)	—	—	uniform	Min = 2.000e4 Max = 3.000e4	Assumed based on Heusler (1976)
Rate constant for oxygen reduction for WP inner overpack (C-m/yr/mol)	—	—	log-uniform	Min = 3.000e7 Max = 3.000e13	Assumed based on Bockris and Reddy (1970); Calvo (1979)
Rate constant for water reduction for WP inner overpack ($C/m^2/yr$)	—	—	log-uniform	Min = 3.200e−3 Max = 3.200e3	Assumed based on Turnbull and Gardner (1982)
Activation energy for oxygen reduction reaction for WP inner overpack (J/mol)	—	—	uniform	Min = 3.000e4 Max = 5.000e4	Assumed based on Calvo (1979)
Activation energy for water reduction reaction for WP inner overpack (J/mol)	—	—	uniform	Min = 2.000e4 Max = 3.000e4	Assumed based on Heusler (1976)
Passive current density for WP outer overpack ($C/m^2/yr$)	—	—	log-uniform	Min = 1.000e4 Max = 1.000e5	Assumed based on Alvarez and Galvele (1984)

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Table 4-3. Listing of reference parameter values for the engineered barrier system failure module used in and proposed to be used in IPA Phase 3 (cont'd)

EBSFAIL Input Parameters					
	TSPA-95 Values		**Proposed IPA Phase 3 Reference Values**		
Parameter	**Distribution**	**Value**	**Distribution**	**Value**	**Source**
Passive current density for WP inner overpack ($C/m^2/yr$)	—	—	log-uniform	Min = 2.000e4 Max = 2.000e5	Assumed based on Alvarez and Galvele (1984)
Factor representing galvanic coupling between outer and inner overpacks	—	—	constant	0 or 1	CNWRA staff best estimate
Reference pH	—	—	constant	9.0	Assumed in Mohanty et al. (1996)
Chloride concentration in water (mol/L)	—	—	log-uniform	Min = 3.000e−3 Max = 3.000	Assumed in Mohanty et al. (1996)
Tortuosity of porous layer scale deposited on WP	—	—	constant	1.0	Assumed in Mohanty et al. (1996)
Porosity of the layer deposited on the WP	—	—	constant	1.0	Assumed in Mohanty et al. (1996)
Fractional coupling strength	—	—	constant	0.0	Assumed in Mohanty et al. (1996)
Chloride multiplication factor	—	—	log-uniform	Min = 1.0 Max = 100.0	Assumed in Mohanty et al. (1996)
Pitting factor	normal	Mean = 4 Min = 1 STD = 1	—	—	—

Table 4-3. Listing of reference parameter values for the engineered barrier system failure module used in and proposed to be used in IPA Phase 3 (cont'd)

EBSFAIL Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
Radius of pits (mm)	constant	0.56	—	—	—
Pit density (pits/WP)	constant	250,000	—	—	—
Pressure at atmospheric contact (atm)	constant	0.86	—	—	—
Pressure at water table (atm)	constant	1.0	—	—	—
a_0 constant in empirical formula for calculating corrosion rate for humid-air corrosion	normal	Mean = 16.9865 STD = 2.8736	—	—	—
a_1 constant in empirical formula for calculating corrosion rate for humid-air corrosion	normal	Mean = 0.6113 STD = 0.0295	—	—	—
a_2 constant in empirical formula for calculating corrosion rate for humid-air corrosion	normal	Mean = −893.76 STD = 231.04	—	—	—
a_3 constant in empirical formula for calculating corrosion rate for humid-air corrosion	normal	Mean = −833.53 STD = 381.97	—	—	—
a_4 constant in empirical formula for calculating corrosion rate for humid-air corrosion	normal	Mean = 2.637e−3 STD = 3.77e−4	—	—	—
b_0 constant in empirical formula for calculating corrosion rate for aqueous corrosion	normal	Mean = 111.506 STD = 10.804	—	—	—
b_1 constant in empirical formula for calculating corrosion rate for aqueous corrosion	normal	Mean = 0.532 STD = 0.0272	—	—	—
b_2 constant in empirical formula for calculating corrosion rate for aqueous corrosion	normal	Mean = −23303.2 STD = 2296.2	—	—	—
b_3 constant in empirical formula for calculating corrosion rate for aqueous corrosion	normal	Mean = −3.193e−4 STD = 3.526e−5	—	—	—

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Table 4-3. Listing of reference parameter values for the engineered barrier system failure module used in and proposed to be used in IPA Phase 3 (cont'd)

EBSFAIL Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Intercept of line representing relationship between critical potential for initiation of localized corrosion of outer overpack and temperature (mV_{SHE})	—	—	uniform	Min = −6.348e2 Max = −5.348e2	Assumed based on Dunn et al. (1996)
Intercept of line representing relationship between slope for initiation of localized corrosion of outer overpack and temperature (mV/decade)	—	—	uniform	Min = −3.450e1 Max = −1.450e1	Assumed based on Dunn et al. (1996)
Intercept of line representing relationship between critical potential for repassivation of localized corrosion of outer overpack and temperature (mV_{SHE})	—	—	uniform	Min = −6.703e2 Max = −5.703e2	Assumed based on Dunn et al. (1996)
Intercept of the line representing relationship between slope for repassivation of localized corrosion of outer overpack and temperature (mV/decade)	—	—	uniform	Min = −1.052e2 Max = −0.882e2	Assumed based on Dunn et al. (1996)
Intercept of line representing relationship between critical potential for initiation of localized corrosion of inner overpack and temperature (mV_{SHE})	—	—	uniform	Min = 1.500e2 Max = 2.500e2	Assumed based on Sridhar et al. (1995)
Intercept of line representing relationship between the slope for initiation of localized corrosion of inner overpack and temperature (mV/decade)	—	—	uniform	Min = −2.600e2 Max = −2.200e2	Assumed based on Sridhar et al. (1995)
Intercept of line representing relationship between critical potential for repassivation of localized corrosion of inner overpack and temperature (mV_{SHE})	—	—	uniform	Min = 3.728e2 Max = 4.728e2	Assumed based on Sridhar et al. (1995)

Table 4-3. Listing of reference parameter values for the engineered barrier system failure module used in and proposed to be used in IPA Phase 3 (cont'd)

EBSFAIL Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Intercept of line representing relationship between slope for repassivation of localized corrosion of outer overpack and temperature (mV/decade)	—	—	uniform	Min = −7.40e1 Max = −5.40e1	Assumed based on Sridhar et al. (1995)
Coefficient in function relating pit penetration and time	—	—	uniform	Min = 8.660e−4 Max = 8.660e−3	Assumed based on Marsh and Taylor (1988)
Exponent in function relating pit penetration and time	—	—	uniform	Min = 4.000e−1 Max = 5.000e−1	Assumed based on Marsh and Taylor (1988)
Pit propagation rate of inner overpack (m/yr)	—	—	uniform	Min = 1.000e−4 Max = 4.000e−4	Assumed in Mohanty et al. (1996)
Potential of galvanic couple between outer and inner overpack when full coupling assumed (V_{SHE})	—	—	uniform	Min = −0.490 Max = −0.430	Assumed based on Scully and Hack (1988)
Pitting corrosion growth rate parameter, C_0	normal	mean = 50.37 STD = 0.99	—	—	—
Pitting corrosion growth rate parameter, C_1	constant	−19,656	—	—	—

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4.4 ENGINEERED BARRIER SYSTEM RELEASE—EBSREL MODULE OF TPA VERSION 3.1

4.4.1 Description of the Proposed IPA Phase 3 Model

The engineered barrier system release module (EBSREL) calculates the time-dependent release of radionuclides after the EBSFAIL module determines the WP has been breached, using temperature, chemical composition of the fluid, and liquid flow rate information provided by NFENV. EBSREL executes the RELEASET stand-alone program, part of EBSPAC (Mohanty et al., 1996). EBSREL takes into account radionuclide decay, generation of daughter products in the chains, temporal variation of inventory in the WP, and spatial variations in the properties of the surrounding material. EBSREL considers only radionuclide releases from SF. Since the WPs are assumed to contain only SF, no study of radionuclide release from glass waste form is made in this model.

The first step in the calculation of liquid releases is to determine if a liquid release is possible at a given time. The release calculation at every time step includes computation of the radionuclide inventory in the solid mass, radionuclide releases from the solid mass into liquid surrounding the WP, generation of new radionuclide inventory in the liquid due to radioactive ingrowth, convective release of mass from inside to the outside the WP, and diffusive losses into the surrounding medium outside the WP.

It is assumed that at the failure time there are at least two pits acting as conduits in a horizontally emplaced WP, located such that water enters through one pit and exits through the other. Another assumption is that one pit is on the side of the WP at a level lower than that of the water entrance pit, which is situated at the top of the horizontally emplaced WP. After the water level in the WP rises to the specified outflow position (a sampled parameter), water begins to flow from the WP along with dissolved radionuclides.

4.4.2 Description of the TSPA-95 Model

It was assumed in TSPA-95 that the near-field environmental conditions exterior to a WP are immediately transferred to the interior of the package after it is penetrated by pitting corrosion. In calculating the release of radionuclides to the host rock from the engineered components of the system, the processes modeled included waste form alteration/dissolution, solubility constraints on the concentration of dissolved radionuclide species, effective diffusion of radionuclides through the degraded WP and other engineered components, and potential for advective transport in localized flow intersecting the drift. After a WP container failed, the waste forms (SF and vitrified DHLW glass) went through alteration/dissolution before the radionuclides were released. The dissolution rate equation for DHLW glass waste form was the same as that used in TSPA-93 (Andrews, et al. 1994).

For radionuclide release from the SF waste form, two distinct release models were considered: instantaneous release and matrix release. The instantaneous release model consisted of species in the gap between fuel pellets and cladding and species on the fuel grain boundaries that are mobile and highly soluble in water. Typically 1 to 2 percent of the inventory of these radionuclides (^{14}C, ^{135}Cs, ^{137}Cs, ^{129}I, ^{99}Tc, and ^{79}Se) was available for instantaneous release. The fraction of these species located in the gap were assumed to be available for immediate release as soon as both WP container and cladding fail.

The SF matrix release model consisted of species in which the release rates of radionuclides were proportional to fuel matrix alteration/dissolution rate. The dissolution rate was determined empirically based on the temperature, total carbonate concentration, and pH of the water contacting it. The SF alteration rate was then determined by multiplying the intrinsic dissolution rate with the available surface area exposed. TSPA-95 assumed that once the waste container had failed the entire waste form surface area was covered with a thin water film. Once the fuel was dissolved, the liquid absorption is limited by the solubility of the radionuclides in the water contacting it. The contaminated water wa transported out of the WP by both diffusive transport and advective release.

Liquid radionuclide concentrations obtained with the alteration/dissolution models was then compared to elemental aqueous solubility limits. If the solubility limit was lower than the modeled dissolution concentration, then the solubility limit concentration wa used for modeling of contaminant transport by dispersion or advection out of the failed WP. Solubility limits were represented as probability distributions rather than as explicit functions of temperature, pressure, and composition dependencies. Nuclide-specific solubilities were obtained from Golder Associates, Inc. (1993) for Cs, Se, and Tc, from Jardine (1991) for Cm, and from Gauthier (1993) for the remainder of the radionuclides.

Depending on groundwater flux through and around the WP, radionuclide release mechanisms were characterized as diffusive release, advective release, or a combination of the two. In the corrosion models described previously, waste containers were assumed to fail by pit corrosion, not by general corrosion. Therefore, release of radionuclides by advection or diffusion was restricted by the number of pits penetrating the partially failed waste container. Advective release was modeled as a combination of the groundwater volumetric flow rate on the WP and the radionuclide concentration at the WP surface. Diffusive release was modeled using a quasi-transient mass transfer model (TRW Environmental Safety Systems, Inc. 1995). Whenever a WP was under dripping flow, the diffusion coefficient in the pits was assumed to be 10^{-7} cm^2/sec.

4.4.3 Comparison of the Engineered Barrier System Release Input Parameter Values

Although the proposed IPA Phase 3 model and TSPA-95 both limit the liquid release of waste by the solubility of the element in contact with the water, there are still a number of differences in the approaches for calculating the release of radionuclides from the WP. The IPA Phase 3 study is proposed to use 43 radionuclides. Radionuclides that the proposed IPA Phase 3 study will consider that TSPA-95 did not are ^{108m}Ag, ^{243}Cm, ^{137}Cs, ^{93}Mo, ^{121m}Sn, ^{90}Sr, and ^{232}U. TSPA-95 considered 39 radionuclides which include ^{232}Th, ^{228}Ra, and ^{93m}Nb that are not included in the IPA Phase 3 study. TSPA-95 did not account for releases due to solid-state diffusion, whereas the proposed IPA Phase 3 model does. Including solid-state diffusion could lead to a shorter travel time to the environment for ^{14}C and other radionuclides.

The reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 for EBS release are presented in table 4-4. There are a number of differences between the input parameter values used in TSPA-95 and proposed to be used in IPA Phase 3. The amount of ^{14}C per kilogram of UO_2 fuel initially located in the gap between the fuel and cladding was larger in TSPA-95 than the proposed to be the reference value in IPA Phase 3. TSPA-95 used a range from 1.42e−5 to 8.5e−5 while the proposed IPA Phase 3 reference value is only a constant value of 6.2e−6. The TSPA-95 value appears to be conservative because the larger amount of ^{14}C in the gap at the time of WP failure, the larger is the release of ^{14}C. A similar difference is seen in the gap fraction of ^{14}C. The gap fraction of

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^{79}Se is also significantly different in the two studies. TSPA-95 used a value of 0.02 for the gap fraction of ^{79}Se, while the proposed IPA Phase 3 reference value is 0.0. Again, the TSPA-95 value will predict a larger amount of ^{79}Se escaping to the environment in a shorter amount of time. The fractional area for capture of flow (called the funnel factor in the TPA Version 3.1 code and catchment area in TSPA-95) is also different in the two studies. The proposed IPA Phase 3 model assumes that the flow above the repository will be divergent so the value must be less than 1. Studies on the proper value for the funnel factor are ongoing, but currently the proposed IPA Phase 3 reference value is 0.9. TSPA-95 used a more conservative value of 4.

In most cases, the solubilities used in TSPA-95 and those proposed as the IPA Phase 3 reference values are very similar, although for the proposed IPA Phase 3 reference values, a triangular distribution is substituted for log-beta distributions in TSPA-95. For those elements that have different values for solubility, the values proposed for the IPA Phase 3 reference parameter values are more conservative (i.e., larger solubilities) than the values in TSPA-95. For curium, TSPA-95 represented the solubility of curium with a log-triangular distribution range from 4.9e−12 to 4.9e−10, whereas the proposed IPA Phase 3 reference values are the same distribution with a range from 1.0e−10 to 1.0e−6. For thorium, TSPA-95 employed a log-uniform distribution that ranges from 1.0e−10 to 1.0e−7, while the proposed IPA Phase 3 reference values include the same distribution with a more conservative range of 1.0e−9 to 1.0e−3. The proposed IPA Phase 3 reference parameter values assumed that there is no solubility controlling phase for cesium, selenium, and technetium so the solubility limits for these elements are assumed to be 1 mol/L. TSPA-95 used a solubility-limited range for each of these elements, all having a mean significantly less than 1 mol/L. Finally, TSPA-95 did not consider strontium so it did not have solubility values listed for it, while the proposed IPA Phase 3 data set does. Table 4-5 shows the comparison of the solubility distributions and values from the two sources. The solubilities are input into the TPA 3.1 code in units of kg/m^3, but are converted to mol/L in table 4-5 for comparison with TSPA-95 values.

4.5 UNSATURATED ZONE FLOW AND TRANSPORT—UZFT MODULE OF TPA VERSION 3.1

4.5.1 Description of the Proposed IPA Phase 3 Model

The unsaturated zone flow and transport module (UZFT) describes the temporal and spatial variation of deep percolation and RT from the repository horizon to the water table. The flow model is based on assuming that gravity drainage occurs in each matrix block with flow preferentially partitioned into the matrix up to a limiting saturation. Interaction between matrix and fracture is assumed to occur only at hydrostratigraphic interfaces. It is assumed the flow system is in a quasi-steady state, so climatic change quickly propagates to depth. RT is simulated using the NEFTRAN II computer program (Olague et al., 1991) and is assumed to occur in 1D flow tubes. NEFTRAN II is operated in the distributed velocity model mode for transport calculations. Convective transport is simulated by moving groups or packets of particles (representing dissolved radionuclides) along the flow field over each time step. Dispersion is simulated by allowing the packets to spread simultaneously with convective transport.

Table 4-4. Listing of reference parameter values for the engineered barrier system release module used in TSPA-95 and proposed for IPA Phase 3

EBSREL Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
Internal WP volume where water can reside (m^3)	—	—	constant	4.83	Assumed in Mohanty et al. (1996)
Porosity of surrounding rock	constant	0.139	constant	0.14	Assumed in Mohanty et al. (1996)
Fractional area for capture of darcy flow onto WP (funnel factor in TPA; catchment area/WP area in TSPA-95)	constant	4	constant	0.9	CNWRA staff best estimate
Flow multiplication factor	—	—	constant	1.0	Assumed in Mohanty et al. (1996)
Subarea wet fraction	—	—	constant	0.3	CNWRA staff best estimate
Fraction of flow hitting WPs	—	—	constant	0.05	CNWRA staff best estimate
Initial defective fraction of WPs per cell	—	—	constant	0.1	CNWRA staff best estimate
Diffusion coefficient of gaseous radionuclides in SF (m^2/sec)	—	—	constant	1.0e−8	Assumed in Mohanty et al. (1996)
SF pellet porosity	—	—	constant	0.3	Assumed in Mohanty et al. (1996)

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Table 4-4. Listing of reference parameter values for the engineered barrier system release module used in TSPA-95 and proposed for IPA Phase 3 (cont'd)

EBSREL Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
pH for fuel leaching	constant	7.0	constant	9.0	Assumed in Mohanty et al. (1996)
Oxygen partial pressure (overpressure) (atm)	constant	0.2	constant	0.2	Assumed in Mohanty et al. (1996)
Carbonate concentration in surrounding water (mol/L)	—	—	constant	2.0e−3	Assumed in Mohanty et al. (1996)
Water level inside the WP expressed as a fraction of the WP internal diameter	—	—	constant	0.50	Assumed in Mohanty et al. (1996)
Initial radius of UO_2 particle (m)	—	—	constant	1.0e−3	Einzinger and Buchanen (1988)
Radius of UO_2 grain (m)	—	—	constant	1.0e−5	Einzinger and Buchanen (1988)
Subgrain fragment radius of UO_2 particle after transgranular fracture (m)	—	—	constant	1.0e−6	Assumed in Mohanty et al. (1996)
Thickness of cladding (m)	constant	6.1e−4	constant	6.1e−4	Smith and Baldwin (1989)
^{14}C/kg of UO_2 fuel (Ci)	constant	1.42e−3	constant	7.2e−4	Assumed in Mohanty et al. (1996)

Table 4-4. Listing of reference parameter values for the engineered barrier system release module used in TSPA-95 and proposed for IPA Phase 3 (cont'd)

EBSREL Input Parameters					
Parameter	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Distribution	Value	Source
^{14}C/kg of UO_2 fuel in Zircaloy cladding and other metals (Ci)	—	—	constant	4.89e−4	Park (1992)
^{14}C/kg of UO_2 fuel in initial Zircaloy oxide and crud metals (Ci)	—	—	constant	2.48e−5	Park (1992)
^{14}C/kg of UO_2 fuel in grain and pellet-cladding gap (Ci)	uniform	Min = 1.42e−5 Max = 8.5e−5	constant	6.2e−6	Park (1992)
Diffusion coefficient for various layers of surrounding medium (near-field transport parameter) (m^2/yr)	—	dependent on saturation	constant	5.6e−5	Assumed in Mohanty et al. (1996)
a_0 constant for model for intrinsic dissolution rate of SF	normal	Mean = 7.323 STD = 0.957	—	—	—
a_1 constant for intrinsic dissolution rate of SF model	normal	Mean = −1585.2 STD = 303.3	—	—	—
a_2 constant for intrinsic dissolution rate of SF model	normal	Mean = 0.2621 STD = 0.0743	—	—	—
a_3 constant for intrinsic dissolution rate of SF model	normal	Mean = −0.1140 STD = 0.0679	—	—	—
a_0 constant for intrinsic dissolution rate of DHLW model	normal	Mean = −0.442 STD = 0.290	—	—	—
a_1 constant for intrinsic dissolution rate of SF model	normal	Mean = 0.0307 STD = 4.58e−3	—	—	—
a_2 constant for intrinsic dissolution rate of SF model	normal	Mean = −1.17 STD = 0.0702	—	—	—

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Table 4-4. Listing of reference parameter values for the engineered barrier system release module used in TSPA-95 and proposed for IPA Phase 3 (cont'd)

EBSREL Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
a_3 constant for intrinsic dissolution rate of SF model	normal	Mean = 0.0793 STD = 6.38e−3	—	—	—
a_4 constant for intrinsic dissolution rate of SF model	normal	Mean = 9.68e−5 STD = 6.95e−5	—	—	—
Surface area of SF (m^2/container)	constant	500	—	—	—
Surface area of DHLW (m^2/container)	uniform	Min = 200 Max = 600	—	—	—
Gap fraction - ^{14}C	uniform	Min = 0.01 Max = 0.06	constant	0.005	Wilson (1990)
Gap fraction - ^{135}Cs	constant	0.02	—	—	—
Gap fraction - ^{129}I	constant	0.02	constant	0.04	Wilson (1990)
Gap fraction - ^{79}Se	constant	0.02	constant	0.00	Wilson (1990)
Gap fraction - ^{99}Tc	constant	0.02	constant	0.01	Wilson (1990)
Retardation coefficient for curium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 2.3 99.9 percentile = 131.2	Assumed in NRC (1995)
Retardation coefficient for plutonium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.3 99.9 percentile = 33.6	Assumed in NRC (1995)
Retardation coefficient for uranium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.003 99.9 percentile = 1.325	Assumed in NRC (1995)
Retardation coefficient for americium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 2.79 99.9 percentile = 165.4	Assumed in NRC (1995)
Retardation coefficient for neptunium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.008 99.9 percentile = 1.81	Assumed in NRC (1995)

Table 4-4. Listing of reference parameter values for the engineered barrier system release module used in TSPA-95 and proposed for IPA Phase 3 (cont'd)

EBSREL Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Retardation coefficient for thorium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.76 99.9 percentile = 77.5	Assumed in NRC (1995)
Retardation coefficient for radium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 3.44 99.9 percentile = 245.2	Assumed in NRC (1995)
Retardation coefficient for lead in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.39 99.9 percentile = 40.07	Assumed in NRC (1995)
Retardation coefficient for cesium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.68 99.9 percentile = 69.4	Assumed in NRC (1995)
Retardation coefficient for iodine in backfill	calculated (see Eq. 6.5-11)	—	constant	1.0	Assumed in NRC (1995)
Retardation coefficient for technicium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.0002 99.9 percentile = 1.016	Assumed in NRC (1995)
Retardation coefficient for nickel in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.08 99.9 percentile = 8.81	Assumed in NRC (1995)
Retardation coefficient for chlorine in backfill	calculated (see Eq. 6.5-11)	—	constant	1.0	Assumed in NRC (1995)
Retardation coefficient for carbon in backfill	calculated (see Eq. 6.5-11)	—	constant	1.0	Assumed in NRC (1995)
Retardation coefficient for selenium in backfill	calculated (see Eq. 6.5-11)	—	log-normal	0.1 percentile = 1.007 99.9 percentile = 1.65	Assumed in NRC (1995)
Retardation coefficient for niobium in backfill	calculated (see Eq. 6.5-11)	—	constant	1.0	Assumed in NRC (1995)
Retardation coefficient for tin in backfill	calculated (see Eq. 6.5-11)	—	constant	1.23	Assumed in NRC (1995)

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Table 4-4. Listing of reference parameter values for the engineered barrier system release module used in TSPA-95 and proposed for IPA Phase 3 (cont'd)

EBSREL Input Parameters					
	TSPA-95 Values		Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Distribution	Value	Source
Retardation coefficient for zirconium in backfill	calculated (see Eq. 6.5-11)	—	constant	1.39	Assumed in NRC (1995)
Retardation coefficient for strontium in backfill	calculated (see Eq. 6.5-11)	—	constant	1.19	Assumed in NRC (1995)

Table 4-5. Listing of the solubility values used in TSPA-95 and proposed as the reference values for IPA Phase 3

Solubility Limits						
	TSPA-1995 Values			Proposed IPA Phase 3 Reference Values		
Element	**Distribution**	**Value (mol/L)**	**Source**	**Distribution**	**Value (mol/L)**	**Source**
Cm	log-triangular	Min = 4.9e−12 Max = 4.9e−10 Peak = 4.9e−11	Jardine (1991)	uniform	Min = 1.0e−10 Max = 1.0e−6 Mean = 5e−7	Fugur (1992, 1993)
U	log-beta	Min = 1.0e−8 Max = 1.0e−2 Peak = 3.2e−5	Gauthier (1993); Wanner and Forest (1992)	triangular	Min = 1.0e−8 Max = 1.0e−2 Peak = 3.2e−5	Gauthier (1993); Wanner and Forest (1992)
Am	uniform	Min = 1.0e−10 Max = 1.0e−6 Mean = 5e−7	Gauthier (1993); Nitsche et al. (1993)	uniform	Min = 1.0e−10 Max = 1.0e−6	Gauthier (1993); Nitsche et al. (1993)
Np	log-beta	Min = 5e−6 Max = 1.0e−2 Peak = 1.4e−4	Gauthier (1993); Nitsche et al. (1993); Dyer (1993)	triangular	Min = 5e−6 Max = 1.0e−2 Peak = 1.4e−4	Gauthier (1993); Nitsche et al. (1993); Dyer (1993)
Pu	uniform	Min = 1.0e−8 Max = 1.0e−6 Mean = 5.1e−7	Gauthier (1993); Nitsche et al. (1993); Dyer (1993)	uniform	Min = 1.0e−8 Max = 1.0e−6	Gauthier (1993); Nitsche et al. (1993); Dyer (1993)
Th	log-uniform	Min = 1.0e−10 Max = 1.0e−7 Mean = 3.2e−9	Assumed in Gauthier (1993)	log-uniform	Min = 1.0e−9 Max = 1.0e−3 Peak = 1.0e−6	Östhols et al (1994); Rai et al (1995)
Ra	log-beta	Min = 1.0e−9 Max = 1.0e−5 Peak = 1.0e−7	Gauthier (1993); Kerrish (1984)	triangular	Min = 1.0e−9 Max = 1.0e−5 Peak = 1.0e−7	Gauthier (1993); Kerrish (1984)
Pb	log-beta	Min = 1.0e−8 Max = 1.0e−5 Peak = 3.2e−7	Gauthier (1993; Andersson (1988); Pei-Lin et al (1985)	triangular	Min = 1.0e−8 Max = 1.0e−5 Peak = 3.2e−7	Gauthier (1993; Andersson (1988); Pei-Lin et al (1985)
Cs	log-triangular	Min = 9.0e−6 Max = 1.6e−2 Peak = 2.9e−3	Golder Associates, Inc. (1993); EPRI (1992)	constant	1.0	No solubility controlling phase; assume 1 mol/L

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Table 4-5. Listing of the solubility values used in TSPA-95 and proposed as the reference values for IPA Phase 3 (cont'd)

Solubility Limits						
	TSPA-1995 Values			Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (mol/L)	Source	Distribution	Value (mol/L)	Source
I	constant	1.0	Assumed based on Gauthier (1993	constant	1.0	Assumed based on Gauthier (1993
Tc	log-triangular	Min = 3.6e−7 Max = 10 Peak = 1.0e−3	Golder Associates, Inc. (1993); EPRI (1992)	constant	1.0	No solubility controlling phase; assume 1 mol/L
Ni	log-beta	Min = 1.0e−6 Max = 1.0e−1 Peak = 1.8e−3	Gauthier (1993); Andersson (1988); Siegel et al. (1993)	triangular	Min = 1.0e−6 Max = 1.0e−1 Peak = 1.8e−3	Gauthier (1993); Andersson (1988); Siegel et al. (1993)
C	constant	1.0	Assumed based on Gauthier (1993	constant	1.0	Assumed based on Gauthier (1993
Se	log-triangular	Min = 1.0e−2 Max = 7.0 Peak = 1.0e−1	Golder Associates, Inc. (1993); EPRI (1992)	constant	1.0	Assume release of radionuclide controlled by waste form dissolution; assume 1 mol/L.
Nb	log-uniform	Min = 1.0e−9 Max = 1.0e−7 Mean = 1.0e−8	Gauthier (1993); Andersson (1988)	log-uniform	Min = 1.0e−9 Max = 1.0e−7	Gauthier (1993); Andersson (1988)
Sn	uniform	Min = 1.0e−11 Max = 1.0e−7 Mean = 5.0e−8	Gauthier (1993); Andersson (1988)	uniform	Min = 1.0e−11 Max = 1.0e−7	Gauthier (1993); Andersson (1988)
Zr	log-uniform	Min = 1.0e−12 Max = 1.0e−7 Mean = 3.2e−10	Gauthier (1993); Andersson (1988)	log-uniform	Min = 1.0e−12 Max = 1.0e−7	Gauthier (1993); Andersson (1988)
Sr	—	—	—	log-triangular	Min = 9.9e−7 Max = 9.9e−3 Peak = 3.2e−5	EQ3 (V.7.1b with thermodynamic database data0.com.R2)

4.5.2 Description of the TSPA-95 Model

The unsaturated zone flow model used in TSPA-95 was partly based on abstractions from the process-level flow model (i.e., the matrix and fracture velocity fields and the partitioning of volumetric flow between fractures and matrix). It also included a fracture-matrix interaction model (to represent intra-unit fracture connectivity and matrix imbibition) and a radionuclide retardation model (to represent chemical interaction between matrix and pore water), neither of which was based on process-level transport modeling. Particle transport was simulated by using velocity fields for both fracture and matrix transport that come from simulations with process-level models. From these simulations, which use the equivalent continuum model (ECM), two families of curves (v_{mat} versus q_{inf} and f_{frac} versus q_{inf}) were generated for each hydrogeologic unit (where v_{mat} is the matrix velocity, f_{frac} is the fraction of the total percolation flux within the fractures, and q_{inf} is the infiltration flux). Because of the lack of an appropriate process-level model, fracture/matrix interaction in the geosphere (e.g., fracture connectivity, imbibition, and matrix diffusion) was simulated directly in the TSPA-95 model by a Markovian process algorithm which modeled a random transition of particles between fracture and matrix modes. The magnitude of this transition rate determined the strength of the fracture/matrix coupling. All rock/water interactions that could serve to retard transport of radionuclides were modeled with an infinite capacity distribution-coefficient model. These distribution coefficients are related to the chemical nature of the individual hydrostratigraphic unit and were classified according to a vitric, devitrified, or zeolitic strata.

4.5.3 Comparison of the Unsaturated Zone Flow and Transport Input Parameter Values

The largest difference in the input parameter values for the two studies is the physical layout of the repository. TSPA-95 modeled not only the main repository area but also the optional additional areas that would be needed if the lower areal loading is used. The proposed IPA Phase 3 model assumes the higher areal loading, so only the smaller repository area needed to be modeled. The division of the repository area is made differently in the two codes. TSPA-95 divided the main repository area into seven columns for the high areal loading case, while the proposed IPA Phase 3 model divides it into seven subareas. For comparison purposes only, these subareas and columns can be matched in the following manner based on locations: Subarea 1 = Column 1; Subarea 2 = Column 2; Subarea 3 = Column 3; Subarea 4 = Column 4; Subarea 5 = Column 5; Subarea 6 = Column 6; Subarea 7 = Column 6. Columns 7–10 in TSPA-95 are used only for the 25 MTU/acre case only and therefore, the proposed IPA Phase 3 reference set of parameter values does not have corresponding subareas. The total thickness of the unsaturated zone varies considerably between TSPA-95 and the values proposed for IPA Phase 3. TSPA-95 employed a much larger thickness (1.28 to 1.39 times as large) for all of the columns. The use of a smaller unsaturated zone is a more conservative estimate because radionuclides will travel through the unsaturated zone faster and reach the critical group sooner.

Studies are currently being conducted to determine the hydrologic parameters in the unsaturated zone of the mountain. Until these studies completed, the best estimate for these parameters are the values in TSPA-95. Those parameters in TSPA-95 comparable to the TPA Version 3.1 code parameters are used as input values. Thus, there are no significant differences between the input values of the two studies at this time. The comparison between the unsaturated zone transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 can be seen in table 4-6.

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Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Tiva Canyon (TCw) matrix van Genuchten alpha (1/m)	constant	0.0081	Schenker et al. (1995)	(not needed — method of Mualem, 1976)	—	NRC (1995)
Paintbrush (PTn) matrix van Genuchten alpha (1/m)	constant	0.0735	Schenker et al. (1995)	(not needed — method of Mualem, 1976)	—	NRC (1995)
Topopah Spring welded (TSw) matrix van Genuchten alpha (1/m)	constant	0.0130	Schenker et al. (1995)	(not needed — method of Mualem, 1976)	—	NRC (1995)
Topopah Sprint vitric (TSv) matrix van Genuchten alpha (1/m)	constant	0.0024	Schenker et al. (1995)	(not needed — method of Mualem, 1976)	—	NRC (1995)
Calico Hills vitric (CHnv) matrix van Genuchten alpha (1/m)	constant	0.0227	Schenker et al. (1995)	(not needed — method of Mualem, 1976)	—	NRC (1995)
Calico Hills zeolitic (CHnz) matrix van Genuchten alpha (1/m)	constant	0.0054	Schenker et al. (1995)	(not needed — method of Mualem, 1976)	—	NRC (1995)
TCw matrix van Genuchten beta	constant	1.607	Schenker et al. (1995)	constant	1.607	Schenker et al. (1995)

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
PTn matrix van Genuchten beta	constant	2.223	Schenker et al. (1995)	constant	2.223	Schenker et al. (1995)
TSw matrix van Genuchten beta	constant	1.710	Schenker et al. (1995)	constant	1.71	Schenker et al. (1995)
TSv matrix van Genuchten beta	constant	2.234	Schenker et al. (1995)	constant	2.234	Schenker et al. (1995)
CHnv matrix van Genuchten beta	constant	2.361	Schenker et al. (1995)	constant	2.361	Schenker et al. (1995)
CHnz matrix van Genuchten beta	constant	1.671	Schenker et al. (1995)	constant	1.671	Schenker et al. (1995)
Prow Pass (PP) matrix van Genuchten beta	—	—	—	uniform	Min = 2.0 Max = 3.4	NRC (1995); Klavetter and Peters (1986)
Upper Crater Flat (CF) matrix van Genuchten beta	—	—	—	uniform	Min = 1.5 Max = 2.4	NRC (1995); Klavetter and Peters (1986)
Bullfrog (BF) matrix van Genuchten beta	—	—	—	uniform	Min = 2.3 Max = 4.2	NRC (1995); Klavetter and Peters (1986)
Middle CF matrix van Genuchten beta	—	—	—	uniform	Min = 1.5 Max = 2.4	NRC (1995); Klavetter and Peters (1986)
TCw residual saturation	constant	0.021	Schenker et al. (1995)	—	—	—
PTn residual saturation	constant	0.154	Schenker et al. (1995)	—	—	—

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
TSw residual saturation	constant	0.045	Schenker et al. (1995)	—	—	—
TSv residual saturation	constant	0.118	Schenker et al. (1995)	—	—	—
CHnv residual saturation	constant	0.097	Schenker et al. (1995)	—	—	—
CHnz residual saturation	constant	0.121	Schenker et al. (1995)	—	—	—
TCw matrix permeability (m^2)	constant	1.3e−18	Schenker et al. (1995)	—	—	—
PTn matrix permeability (m^2)	constant	1.1e−15	Schenker et al. (1995)	—	—	—
TSw matrix permeability (m^2)	constant	2.0e−18	Schenker et al. (1995)	constant	2.0e−18	Schenker et al. (1995)
TSv matrix permeability (m^2)	constant	1.0e−18	Schenker et al. (1995)	constant	1.0e−18	Schenker et al. (1995)
CHnv matrix permeability (m^2)	constant	1.0e−16	Schenker et al. (1995)	constant	1.0e−16	Schenker et al. (1995)
CHnz matrix permeability (m^2)	constant	1.6e−18	Schenker et al. (1995)	constant	1.6e−18	Schenker et al. (1995)
PP matrix permeability (m^2)	—	—	—	log-normal	0.1 percentile = 1.9e−16 99.9 percentile = 9.6e−16	NRC (1995); Peters et al. (1984)
Upper CF matrix permeability (m^2)	—	—	—	log-normal	0.1 percentile = 5.1e−18 99.9 percentile = 1.5e−17	NRC (1995); Peters et al. (1984)
BF matrix permeability (m^2)	—	—	—	log-normal	0.1 percentile = 3.5e−16 99.9 percentile = 4.4e−16	NRC (1995); Peters et al. (1984)

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
Parameter	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Parameter**	**Source**	**Distribution**	**Value**	**Source**
Middle CF matrix permeability (m^2)	—	—	—	log-normal	0.1 percentile = 4.1e−18 99.9 percentile = 1.6e−17	NRC (1995); Peters et al. (1984)
TCw matrix bulk density (kg/m^3)	constant	2285	Schenker et al. (1995)	—	—	—
PTn matrix bulk density (kg/m^3)	constant	1419	Schenker et al. (1995)	—	—	—
TSw matrix bulk density (kg/m^3)	constant	2247	Schenker et al. (1995)	constant (grain density)	2247	Schenker et al. (1995)
TSv matrix bulk density (kg/m^3)	constant	2308	Schenker et al. (1995)	constant (grain density)	2308	Schenker et al. (1995)
CHnv matrix bulk density (kg/m^3)	constant	1737	Schenker et al. (1995)	constant (grain density)	1737	Schenker et al. (1995)
CHnz matrix bulk density (kg/m^3)	constant	1746	Schenker et al. (1995)	constant (grain density)	1746	Schenker et al. (1995)
density (kg/m^3)	—	—	—	constant (grain density)	2590	Peters et al. (1984)
Upper CF matrix bulk density (kg/m^3)	—	—	—	constant (grain density)	2270	Peters et al. (1984)

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Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

tbl. 4-6 cont

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
BF matrix bulk density (kg/m^3)	—	—	—	constant (grain density)	2630	Peters et al. (1984)
Middle CF matrix bulk density (kg/m^3)	—	—	—	constant (grain density)	2270	Peters et al. (1984)
Inlet area (m^2)	—	—	—	constant	Subarea 1: 5.4e5 Subarea 2: 5.4e5 Subarea 3: 5.4e5 Subarea 4: 5.4e5 Subarea 5: 5.4e5 Subarea 6: 5.4e5	CNWRA staff best estimate
TCw matrix porosity	constant	0.087	Schenker et al. (1995)	—	—	—
PTn matrix porosity	constant	0.421	Schenker et al. (1995)	—	—	—
TSw matrix porosity	constant	0.139	Schenker et al. (1995)	constant	0.139	Schenker et al. (1995)
TSv matrix porosity	constant	0.065	Schenker et al. (1995)	constant	0.065	Schenker et al. (1995)
CHnv matrix porosity	constant	0.331	Schenker et al. (1995)	constant	0.331	Schenker et al. (1995)
CHnz matrix porosity	constant	0.306	Schenker et al. (1995)	constant	0.306	Schenker et al. (1995)
PP matrix porosity	—	—	—	uniform	Min = 0.24 Max = 0.40	NRC (1995); Peters et al. (1984)

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			**Proposed IPA Phase 3 Reference Values**		
Parameter	**Distribution**	**Parameter**	**Source**	**Distribution**	**Value**	**Source**
Upper CF matrix porosity	—	—	—	uniform	Min = 0.18 Max = 0.30	NRC (1995); Peters et al. (1984)
BF matrix porosity	—	—	—	uniform	Min = 0.19 Max = 0.32	NRC (1995); Peters et al. (1984)
Middle CF matrix porosity	—	—	—	uniform	Min = 0.18 Max = 0.30	NRC (1995); Peters et al. (1984)
TCw fracture permeability (m^2)	constant (Bulk)	1.8e-12	Schenker et al. (1995)	constant	1.8e-12	Schenker et al. (1995)
PTn fracture permeability (m^2)	constant (Bulk)	5.4e-13	Schenker et al. (1995)	constant	5.4e-13	Schenker et al. (1995)
TSw fracture permeability (m^2)	constant (Bulk)	1.8e-12	Schenker et al. (1995)	constant	1.8e-12	Schenker et al. (1995)
Tsv fracture permeability (m^2)	constant (Bulk)	1.8e-12	Schenker et al. (1995)	constant	1.8e-12	Schenker et al. (1995)
CHnv fracture permeability (m^2)	constant (Bulk)	5.4e-13	Schenker et al. (1995)	constant	5.4e-13	Schenker et al. (1995)
CHnz fracture permeability (m^2)	constant (Bulk)	1.2e-13	Schenker et al. (1995)	constant	1.2e-13	Schenker et al. (1995)
PP fracture permeability (m^2)	—	—	—	log-normal	0.1 percentile = 3.9-17 99.9 percentile = 8.1e-17	NRC (1995); Klavetter and Peters (1986)
Upper CF fracture permeability (m^2)	—	—	—	log-normal	0.1 percentile = 6.7e-16 99.9 percentile = 9.8e-16	NRC (1995); Klavetter and Peters (1986)

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Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
BF fracture permeability (m^2)	—	—	—	log-normal	0.1 percentile = 4.9e−17 99.9 percentile = 6.4e−17	NRC (1995); Klavetter and Peters (1986)
Middle CF fracture permeability (m^2)	—	—	—	log-normal	0.1 percentile = 6.7e−16 99.9 percentile = 9.8e−16	NRC (1995); Klavetter and Peters (1986)
Fracture porosity	constant (all units)	1.00e−3	Schenker et al. (1995)	constant (all units)	1.00e−3	Schenker et al. (1995)
Fracture van Genuchten alpha (1/m)	constant	10	Schenker et al. (1995)	(not needed - method of Mualem, 1976)	—	NRC (1995)
Fracture van Genuchten beta	constant	5	Schenker et al. (1995)	constant	5	Schenker et al. (1995)
Fracture residual saturation	constant	0	Schenker et al. (1995)	constant	0	Ortiz et al. (1985)
Column 1 TSw thickness (m)	constant	105	Wittwer et al. (1995)	constant (Subarea 1)	0	CNWRA staff best estimate
Column 1 TSv thickness (m)	constant	8	Wittwer et al. (1995)	constant (Subarea 1)	0	CNWRA staff best estimate
Column 1 CHnv thickness (m)	constant	92	Wittwer et al. (1995)	constant (Subarea 1)	125	CNWRA staff best estimate
Column 1 CHnz thickness (m)	constant	24	Wittwer et al. (1995)	(CHnv and CHnz combined)	—	CNWRA staff best estimate

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameter	Source	Distribution	Value	Source
Column 1 PPn thickness (m)	constant	115	Wittwer et al. (1995)	constant (Subarea 1)	30	CNWRA staff best estimate
Column 1 upper CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 1)	113	CNWRA staff best estimate
Column 1 BF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 1)	0	CNWRA staff best estimate
Column 1 middle CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 1)	0	CNWRA staff best estimate
Total thickness Column 1 (m)	constant	345	Wittwer et al. (1995)	constant (Subarea 1)	268	CNWRA staff best estimate
Column 2 TSw thickness (m)	constant	176	Wittwer et al. (1995)	constant (Subarea 2)	43	CNWRA staff best estimate
Column 2 TSv thickness (m)	constant	8	Wittwer et al. (1995)	constant (Subarea 2)	0	CNWRA staff best estimate
Column 2 CHnv thickness (m)	constant	72	Wittwer et al. (1995)	constant (Subarea 2)	153	CNWRA staff best estimate
Column 2 CHnz thickness (m)	constant	50	Wittwer et al. (1995)	(CHnv and Chnz combined)	0	CNWRA staff best estimate
Column 2 PPn thickness (m)	constant	38	Wittwer et al. (1995)	constant (Subarea 2)	37	CNWRA staff best estimate
Column 2 upper CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 2)	35	CNWRA staff best estimate
Column 2 BF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 2)	0	CNWRA staff best estimate

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Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Column 2 middle CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 2)	0	CNWRA staff best estimate
Total thickness Column 2 (m)	constant	344	Wittwer et al. (1995)	constant (Subarea 2)	268	CNWRA staff best estimate
Column 3 TSw thickness (m)	constant	87	Wittwer et al. (1995)	constant (Subarea 3)	0	CNWRA staff best estimate
Column 3 TSv thickness (m)	constant	8	Wittwer et al. (1995)	constant	0	CNWRA staff best estimate
Column 3 CHnv thickness (m)	constant	105	Wittwer et al. (1995)	constant (Subarea 3)	53	CNWRA staff best estimate
Column 3 CHnz thickness (m)	constant	32	Wittwer et al. (1995)	(CHnv and Chnz combined)	—	CNWRA staff best estimate
Column 3 PPn thickness (m)	constant	126	Wittwer et al. (1995)	constant (Subarea 3)	40	CNWRA staff best estimate
Column 3 upper CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 3)	169	CNWRA staff best estimate
Column 3 BF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 3)	6	CNWRA staff best estimate
Column 3 middle CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 3)	0	CNWRA staff best estimate
Total thickness Column 3 (m)	constant	358	Wittwer et al. (1995)	constant (Subarea 3)	268	CNWRA staff best estimate
Column 4 TSw thickness (m)	constant	147	Wittwer et al. (1995)	constant (Subarea 4)	36	CNWRA staff best estimate

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameter	Source	Distribution	Value	Source
Column 4 TSv thickness (m)	constant	8	Wittwer et al. (1995)	constant (Subarea 4)	0	CNWRA staff best estimate
Column 4 CHnv thickness (m)	constant	87	Wittwer et al. (1995)	constant (Subarea 4)	136	CNWRA staff best estimate
Column 4 CHnz thickness (m)	constant	57	Wittwer et al. (1995)	(CHnv and CHnz combined)	—	CNWRA staff best estimate
Column 4 PPn thickness (m)	constant	61	Wittwer et al. (1995)	constant (Subarea 4)	31	CNWRA staff best estimate
Column 4 upper CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 4)	66	CNWRA staff best estimate
Column 4 BF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 4)	0	CNWRA staff best estimate
Column 4 middle CF thickness (m)	constant	0	Wittwer et al. (1995)	costant (Subarea 4)	0	CNWRA staff best estimate
Total thickness Column 4 (m)	constant	359	Wittwer et al. (1995)	constant (Subarea 4)	269	CNWRA staff best estimate
Column 5 TSw thickness (m)	constant	35	Wittwer et al. (1995)	constant (Subarea 5)	0	CNWRA staff best estimate
Column 5 TSv thickness (m)	constant	7	Wittwer et al. (1995)	(TSv and TSw combined)	0	CNWRA staff best estimate
Column 5 CHnv thickness (m)	constant	132	Wittwer et al. (1995)	constant (Subarea 5)	35	CNWRA staff best estimate

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Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Column 5 CHnz thickness (m)	constant	40	Wittwer et al. (1995)	(CHnv and CHnz combined)	—	CNWRA staff best estimate
Column 5 PPn thickness (m)	constant	158	Wittwer et al. (1995)	constant (Subarea 5)	37	CNWRA staff best estimate
Column 5 upper CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 5)	158	CNWRA staff best estimate
Column 5 BF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 5)	38	CNWRA staff best estimate
Column 5 middle CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 5)	0	CNWRA staff best estimate
Total thickness Column 5 (m)	constant	372	Wittwer et al. (1995)	constant (Subarea 5)	268	CNWRA staff best estimate
Column 6 TSw thickness (m)	constant	113	Wittwer et al. (1995)	constant (Subarea 6)	0	CNWRA staff best estimate
Column 6 TSv thickness (m)	constant	7	Wittwer et al. (1995)	(TSv and TSw combined)	0	CNWRA staff best estimate
Column 6 CHnv thickness (m)	constant	102	Wittwer et al. (1995)	constant (Subarea 6)	103	CNWRA staff best estimate
Column 6 CHnz thickness (m)	constant	43	Wittwer et al. (1995)	(CHnv and CHnz combined)	—	CNWRA staff best estimate
Column 6 PPn thickness (m)	constant	105	Wittwer et al. (1995)	constant (Subarea 6)	26	CNWRA staff best estimate

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Column 6 upper CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 6)	138	CNWRA staff best estimate
Column 6 BF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 6)	0	CNWRA staff best estimate
Column 6 Middle CF thickness (m)	constant	0	Wittwer et al. (1995)	constant (Subarea 6)	0	CNWRA staff best estimate
Total thickness Column 6 (m)	constant	370	Wittwer et al. (1995)	constant (Subarea 6)	267	CNWRA staff best estimate
Column 7 TSw thickness (m)	constant (25 MTU/acre Case only)	151	Wittwer et al. (1995)	—	—	—
Column 7 TSv thickness (m)	constant (25 MTU/acre Case only)	8	Wittwer et al. (1995)	—	—	—
Column 7 CHnv thickness (m)	constant (25 MTU/acre Case only)	55	Wittwer et al. (1995)	—	—	—
Column 7 CHnz thickness (m)	constant (25 MTU/acre Case only)	68	Wittwer et al. (1995)	—	—	—
Column 7 PPn thickness (m)	constant (25 MTU/acre Case only)	0	Wittwer et al. (1995)	—	—	—
Column 7 Upper CF thickness (m)	constant (25 MTU/acre Case only)	0	Wittwer et al. (1995)	—	—	—

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Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Column 7 BF thickness (m)	constant (25 MTU/acre Case only)	0	Wittwer et al. (1995)	—	—	—
Column 7 Middle CF thickness (m)	constant (25 MTU/acre Case only)	0	Wittwer et al. (1995)	—	—	—
Total thickness Column 7 (m)	constant (25 MTU/acre Case only)	282	Wittwer et al. (1995)	—	—	—
Column 8 TSw thickness (m)	constant (25 MTU/acre Case only)	105	Wittwer et al. (1995)	—	—	—
Column 8 TSv thickness (m)	constant (25 MTU/acre Case only)	15	Wittwer et al. (1995)	—	—	—
Column 8 CHnv thickness (m)	constant (25 MTU/acre Case only)	54	Wittwer et al. (1995)	—	—	—
Column 8 CHnz thickness (m)	constant (25 MTU/acre Case only)	18	Wittwer et al. (1995)	—	—	—
Column 8 PPn thickness (m)	constant (25 MTU/acre Case only)	48	Wittwer et al. (1995)	—	—	—
Total thickness Column 8 (m)	constant (25 MTU/acre Case only)	240	Wittwer et al. (1995)	—	—	—

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Column 9 TSw thickness (m)	constant (25 MTU/acre Case only)	80	Wittwer et al. (1995)	—	—	—
Column 9 TSv thickness (m)	constant (25 MTU/acre Case only)	15	Wittwer et al. (1995)	—	—	—
Column 9 CHnv thickness (m)	constant (25 MTU/acre Case only)	63	Wittwer et al. (1995)	—	—	—
Column 9 CHnz thickness (m)	constant (25 MTU/acre Case only)	21	Wittwer et al. (1995)	—	—	—
Column 9 PPn thickness (m)	constant (25 MTU/acre Case only)	56	Wittwer et al. (1995)	—	—	—
Total thickness Column 9 (m)	constant (25 MTU/acre Case only)	235	Wittwer et al. (1995)	—	—	—
Column 10 TSw thickness (m)	constant (25 MTU/acre Case only)	85	Wittwer et al. (1995)	—	—	—
Column 10 TSv thickness (m)	constant (25 MTU/acre Case only)	15	Wittwer et al. (1995)	—	—	—
Column 10 CHnv thickness (m)	constant (25 MTU/acre Case only)	47	Wittwer et al. (1995)	—	—	—

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Parameter	Source	Distribution	Value	Source
Column 10 CHnz thickness (m)	constant (25 MTU/acre Case only)	16	Wittwer et al. (1995)	—	—	—
Column 10 PPn thickness (m)	constant (25 MTU/acre Case only)	42	Wittwer et al. (1995)	—	—	—
Total thickness Column 10 (m)	constant (25 MTU/acre Case only)	205	Wittwer et al. (1995)	—	—	—
Subarea 7 Total TSw thickness (welded + vitric) (m)	—	—	—	constant	48	CNWRA staff best estimate
Subarea 7 Total CHn thickness (welded + vitric) (m)	—	—	—	constant	113	CNWRA staff best estimate
Subarea 7 PPn thickness (m)	—	—	—	constant	44	CNWRA staff best estimate
Subarea 7 upper CF thickness (m)	—	—	—	constant	63	CNWRA staff best estimate
Subarea 7 BF thickness (m)	—	—		constant	0	CNWRA staff best estimate
Subarea 7 Total thickness (m)	—	—	—	constant	268	CNWRA staff best estimate

Table 4-6. Comparison of the unsaturated zone flow and transport reference parameter values used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

UZFT Input Values						
Parameter	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Parameter**	**Source**	**Distribution**	**Value**	**Source**
Repository Area upper block (m^2)	constant (25 and 83 MTU /acre Cases)	3.766e6	CRWMS M&O (1994b)	constant	3.77e6	CRWMS M&O (1994b)
Repository Area lower block (m^2)	constant (25 MTU/acre Case only)	8.83e5	CRWMS M&O (1994b)	—	—	—
Repository Area optional area B (m^2)	constant (25 MTU/acre Case only)	1.777e6	CRWMS M&O (1994b)	—	—	—
Repository Area optional Area C (m^2)	constant (25 MTU/acre Case only)	1.467e6	TSPA 95	—	—	—
Repository Area optional Area D (m^2)	constant (25 MTU/acre Case only)	2.369e6	CRWMS M&O (1994b)	—	—	—
Fracture Rd values	—	—	—	constant (for all nuclides and areas)	1.0	CNWRA staff conservative estimation of no retardation
Longitudinal dispersivity for fracture and matrix flow	—	—	—	log-normal	Min = 0.3 Max = 30.0	Assumed in NRC (1995). Matrix dispersivity is conservatively assumed to be equal to fracture dispersivity

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Distributions used to estimate the sorption coefficient values (K_d values) in the TSPA-95 and proposed to be used in IPA Phase 3 are listed in table 4-7. TSPA-95 considered more elements than does the proposed IPA Phase 3 reference set of parameter values. The elements that TSPA-95 included and the proposed IPA Phase 3 reference set of parameter values does not are actinium, samarium, protactinium, and palladium. The proposed IPA Phase 3 reference parameter values use log-uniform K_d distributions while TSPA-95 used uniform K_d distributions. The parameter values for IPA Phase 3, with a factor of 100 between the minimum value and the maximum value, tend to have a larger range than the values in TSPA-95, which had a factor among 5 and 20 between the minimum and the maximum for most of the values. A significant difference is taken to be at least a factor of 10 difference between the two studies for the minimum or maximum values of the distribution for at least two hydrostratigraphic units (unless the minimum value is zero, in which case judgment is used). For the proposed IPA Phase 3 data set, the K_d for niobium has a constant value of zero, while in TSPA-95, it ranged from 0.1 to 2.0. For technetium, the proposed IPA Phase 3 reference value is a range from 0 to 0.042, while TSPA-95 had a constant value of 0. The extreme values of the ranges of values for lead and zirconium are much higher in TSPA-95 than proposed for IPA Phase 3. For a number of elements, the maximum values proposed for IPA Phase 3 are larger than the maximum values in TSPA-95 by a factor of 10–100 for several hydrostratigraphic units: americium, cesium, radium, strontium, and tin. A lower K_d will lead to a prediction of a faster travel time of the radionuclides through the unsaturated zone.

4.6 SATURATED ZONE FLOW AND TRANSPORT—SZFT MODULE OF TPA VERSION 3.1

4.6.1 Description of the Proposed IPA Phase 3 Model

The saturated zone flow and transport module (SZFT) describes RT in the saturated zone from the location where radionuclides enter the water table immediately below the repository, to receptor sites in the Amargosa Desert. The SZFT transport module consists of an array of 1D streamtubes originating at the water table below the repository and terminating at one or more radionuclide receptor locations. RT in the SZFT module is simulated using the NEFTRAN II code (Olague et al., 1991) which calculates the radionuclide groundwater concentration at the down-gradient receptor location. The code takes into account streamtube geometries, seepage velocities, and longitudinal dispersivities to assess the extent of hydrodynamic dispersion that may occur as contaminant plumes move through relatively long, heterogeneous flow paths.

4.6.2 Description of the TSPA-95 Model

The saturated-zone flux affected the arrival time of radionuclides at the accessible-environment boundary as well as the degree of mixing and dilution in the groundwater of the tuff aquifer prior to its extraction and use. The saturated-zone flux distribution in TSPA-95 used the entire 2D distribution of nodal fluxes to represent the possible range of spatially averaged 1D flux in the saturated zone. Since RIP only considers 1D flux, the entire 2D distribution of steady-state nodal velocities (or fluxes) was sampled from the distribution to determine the 1D saturated zone flux for any given realization. The entire flux distribution incorporated the effects of large-scale spatial heterogeneity of aquifer properties. Small-scale heterogeneity was included through the use of dispersion in the solution of the 1D advection-dispersion equation. Because of the 1D nature of the solution algorithm, only longitudinal dispersion was simulated (i.e., there was no transverse dispersion).

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values

K_d Values						
Hydrostratigraphy (Rock Type)	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Element: Am						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.081 Max = 8.1	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.081 Max = 8.1	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.081 Max = 8.1	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.17 Max = 17	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.45 Max = 45	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.136 Max = 13.6	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.014 Max = 1.4	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.014 Max = 1.4	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.136 Max = 13.6	NRC (1995); Meijer (1990)
Element: **Ac**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	—	—	—
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	—	—	—
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	—	—	—
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Element: **C**						
Topopah Spring, welded (D)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Topopah Spring, vitrophyre (V)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Calico Hills/Prow Pass, vitric (V)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Calico Hills/Prow Pass, zeolitic (Z)	constant	0	TSPA-1995	constant	0	Assumed in NRC (1995)
Prow Pass, welded (D)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

Hydrostratigraphy (Rock Type)	K_d Values					
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Crater Flat, upper (Z)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Bullfrog, nonwelded (Z)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Bullfrog, welded (D)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Crater Flat, middle (Z)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Element: **Cl**						
Topopah Spring, welded (D)	constant	0	Based on Meijer (1995)	constant	0	assumed
Topopah Spring, vitrophyre (V)	constant	0	Based on Meijer (1995)	constant	0	assumed
Calico Hills/Prow Pass, vitric (V)	constant	0	Based on Meijer (1995)	constant	0	assumed
Calico Hills/Prow Pass, zeolitic (Z)	constant	0	Based on Meijer (1995)	constant	0	assumed
Prow Pass, welded (D)	constant	0	Based on Meijer (1995)	constant	0	assumed
Crater Flat, upper (Z)	constant	0	Based on Meijer (1995)	constant	0	assumed
Bullfrog, nonwelded (Z)	constant	0	Based on Meijer (1995)	constant	0	assumed
Bullfrog, welded (D)	constant	0	Based on Meijer (1995)	constant	0	assumed

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Hydrostratigraphy (Rock Type)	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Crater Flat, middle (Z)	constant	0	Based on Meijer (1995)	constant	0	assumed
Element: **Cm**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 1.0	Based on Meijer (1995)	log-uniform	Min = 0.045 Max = 4.5	NRC (1995); Codell et al. (1992)
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1.0	Based on Meijer (1995)	log-uniform	Min = 0.045 Max = 4.5	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1.0	Based on Meijer (1995)	log-uniform	Min = 0.328 Max = 32.8	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 2.0	Based on Meijer (1995)	log-uniform	Min = 0.166 Max = 16.6	NRC (1995); Codell et al. (1992)
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 1.0	Based on Meijer (1995)	log-uniform	Min = 0.116 Max = 11.6	NRC (1995); Codell et al. (1992)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 2.0	Based on Meijer (1995)	log-uniform	Min = 0.132 Max = 13.2	NRC (1995); Codell et al. (1992)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 2.0	Based on Meijer (1995)	log-uniform	Min = 0.12 Max = 12.0	NRC (1995); Codell et al. (1992)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 1.0	Based on Meijer (1995)	log-uniform	Min = 0.12 Max = 12.0	NRC (1995); Codell et al. (1992)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 2.0	Based on Meijer (1995)	log-uniform	Min = 0.132 Max = 13.2	NRC (1995); Codell et al. (1992)
Element: **Cs**						
Topopah Spring, welded (D)	uniform	Min = 0.02 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.036 Max = 3.6	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	uniform	Min = 0.01 Max = 0.1	TSPA-1995	log-uniform	Min = 0.036 Max = 3.6	NRC (1995); Meijer (1990)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

	K_d Values					
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Calico Hills/Prow Pass, vitric (V)	uniform	Min = 0.01 Max = 0.1	Based on Meijer (1995)	log-uniform	Min = 0.024 Max = 2.4	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.5 Max = 5	Based on Meijer (1995)	log-uniform	Min = 2.2 Max = 220.0	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	uniform	Min = 0.02 Max = 1.0	TSPA-1995	log-uniform	Min = 0.22 Max = 22.0	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	uniform	Min = 0.5 Max = 5	Based on Meijer (1995)	log-uniform	Min = 1.76 Max = 176.0	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	uniform	Min = 0.5 Max = 5	Based on Meijer (1995)	log-uniform	Min = 0.32 Max = 32.0	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	uniform	Min = 0.02 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.32 Max = 32.0	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	uniform	Min = 0.5 Max = 5	Based on Meijer (1995)	log-uniform	Min = 1.76 Max = 176.0	NRC (1995); Meijer (1990)
Element: **I**						
Topopah Spring, welded (D)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Topopah Spring, vitrophyre (V)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Calico Hills/Prow Pass, vitric (V)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Calico Hills/Prow Pass, zeolitic (Z)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Prow Pass, welded (D)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

Hydrostratigraphy (Rock Type)	K_d Values					
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Crater Flat, upper (Z)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Bullfrog, nonwelded (Z)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Bullfrog, welded (D)	constant	0	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Element: **Nb**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	constant	0	Assumed in NRC (1995)
Element: **Ni**						

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

Hydrostratigraphy (Rock Type)	TSPA-95 Values: Distribution	TSPA-95 Values: Value (m^3/kg)	TSPA-95 Values: Source	Proposed IPA Phase 3 Reference Values: Distribution	Proposed IPA Phase 3 Reference Values: Value (m^3/kg)	Proposed IPA Phase 3 Reference Values: Source
Topopah Spring, welded (D)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 3.7e−4 Max = 0.037	NRC (1995); Codell et al. (1992)
Topopah Spring, vitrophyre (V)	beta	*Unsat. Zone* Min = 0 Max = 0.1 *Sat. Zone* Min = 0 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 3.7e−4 Max = 0.037	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, vitric (V)	beta	*Unsat. Zone* Min = 0 Max = 0.1 *Sat. Zone* Min = 0 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.0027 Max = 0.27	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, zeolitic (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0014 Max = 0.14	NRC (1995); Codell et al. (1992)
Prow Pass, welded (D)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0009 Max = 0.09	NRC (1995); Codell et al. (1992)
Crater Flat, upper (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0011 Max = 0.11	NRC (1995); Codell et al. (1992)
Bullfrog, nonwelded (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.001 Max = 0.1	NRC (1995); Codell et al. (1992)
Bullfrog, welded (D)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.001 Max = 0.1	NRC (1995); Codell et al. (1992)
Crater Flat, middle (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0011 Max = 0.11	NRC (1995); Codell et al. (1992)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Element: **Np**						
Topopah Spring, welded (D)	beta	*Unsat. Zone* Min = 0 Max = 0.006 *Sat. Zone* Min = 0 Max = 0.01	Based on Meijer (1995)	log-uniform	Min = 4.5e−4 Max = 0.045	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	exponential	Min = 0 Max = 0.015	Based on Meijer (1995)	log-uniform	Min = 4.5e−4 Max = 0.045	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	exponential	Min = 0 Max = 0.015	Based on Meijer (1995)	log-uniform	Min = 4.5e−4 Max = 0.045	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	beta	*Unsat. Zone* Min = 0 Max = 0.003 *Sat. Zone* Min = 0 Max = 0.02	Based on Meijer (1995)	log-uniform	Min = 2.7e−4 Max = 0.027	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	beta	*Unsat. Zone* Min = 0 Max = 0.006 *Sat. Zone* Min = 0 Max = 0.01	Based on Meijer (1995)	log-uniform	Min = 5.1e−4 Max = 0.051	NRC (1995); Meijer (1990)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Crater Flat, upper (Z)	beta	*Unsat. Zone* Min = 0 Max = 0.003 *Sat. Zone* Min = 0 Max = 0.012	Based on Meijer (1995)	log-uniform	Min = 2.2e−4 Max = 0.022	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	beta	*Unsat. Zone* Min = 0 Max = 0.003 *Sat. Zone* Min = 0 Max = 0.012	Based on Meijer (1995)	log-uniform	Min = 5.1e−4 Max = 0.051	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	beta	*Unsat. Zone* Min = 0 Max = 0.006 *Sat. Zone* Min = 0 Max = 0.012	Based on Meijer (1995)	log-uniform	Min = 5.1e−4 Max = 0.051	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	beta	*Unsat. Zone* Min = 0 Max = 0.003 *Sat. Zone* Min = 0 Max = 0.012	Based on Meijer (1995)	log-uniform	Min = 2.2e−4 Max = 0.022	NRC (1995); Meijer (1990)
Element: **Pa**						
Topopah Spring, welded (D)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Hydrostratigraphy (Rock Type)	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Topopah Spring, vitrophyre (V)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, vitric (V)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Prow Pass, welded (D)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Crater Flat, upper (Z)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Bullfrog, nonwelded (Z)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Bullfrog, welded (D)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Crater Flat, middle (Z)	uniform	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Element: **Pb**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 6.8e−4 Max = 0.068	NRC (1995); Codell et al. (1992)
Topopah Spring, vitrophyre (V)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 6.8e−4 Max = 0.068	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, vitric (V)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0049 Max = 0.49	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0025 Max = 0.25	NRC (1995); Codell et al. (1992)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Hydrostratigraphy (Rock Type)	**Distribution**	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0017 Max = 0.17	NRC (1995); Codell et al. (1992)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0020 Max = 0.20	NRC (1995); Codell et al. (1992)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0018 Max = 0.18	NRC (1995); Codell et al. (1992)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0018 Max = 0.18	NRC (1995); Codell et al. (1992)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.0020 Max = 0.20	NRC (1995); Codell et al. (1992)
Element: **Pd**						
Topopah Spring, welded (D)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—
Topopah Spring, vitrophyre (V)	beta	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0 Max = 0.1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, zeolitic (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—
Prow Pass, welded (D)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—
Crater Flat, upper (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—
Bullfrog, nonwelded (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

Hydrostratigraphy (Rock Type)	K_d Values					
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Bullfrog, welded (D)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—
Crater Flat, middle (Z)	beta	Min = 0 Max = 0.5	Based on Meijer (1995)	—	—	—
Element: **Pu**						
Topopah Spring, welded (D)	beta	*Unsat. Zone* Min = 0.02 Max = 0.2 *Sat. Zone* Min = 0.05 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.017 Max = 1.7	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	beta	*Unsat. Zone* Min = 0.02 Max = 0.2 *Sat. Zone* Min = 0.05 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0. 017 Max = 1.7	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	beta	*Unsat. Zone* Min = 0.05 Max = 0.2 *Sat. Zone* Min = 0.05 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0. 017 Max = 1.7	NRC (1995); Meijer (1990)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Calico Hills/Prow Pass, zeolitic (Z)	beta	*Unsat. Zone* Min = 0.03 Max = 0.2 *Sat. Zone* Min = 0.03 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.0066 Max = 0.66	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	beta	*Unsat. Zone* Min = 0.02 Max = 0.2 *Sat. Zone* Min = 0.05 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.013 Max = 1.3	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	beta	*Unsat. Zone* Min = 0.03 Max = 0.2 *Sat. Zone* Min = 0.03 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.0053 Max = 0.53	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	beta	*Unsat. Zone* Min = 0.03 Max = 0.2 *Sat. Zone* Min = 0.03 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.0094 Max = 0.94	NRC (1995); Meijer (1990)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Hydrostratigraphy (Rock Type)	**Distribution**	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Bullfrog, welded (D)	beta	*Unsat. Zone* Min = 0.02 Max = 0.2 *Sat. Zone* Min = 0.05 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.0094 Max = 0.94	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	beta	*Unsat. Zone* Min = 0.03 Max = 0.2 *Sat. Zone* Min = 0.03 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.0053 Max = 0.53	NRC (1995); Meijer (1990)
Element: **Ra**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.15 Max = 15.0	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	uniform	*Unsat. Zone* Min = 0.05 Max = 0.1 *Sat. Zone* Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.15 Max = 15.0	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	uniform	*Unsat. Zone* Min = 0.05 Max = 0.1 *Sat. Zone* Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.15 Max = 15.0	NRC (1995); Meijer (1990)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

Hydrostratigraphy (Rock Type)	K_d Values: TSPA-95 Values: Distribution	Value (m^3/kg)	Source	Proposed IPA Phase 3 Reference Values: Distribution	Value (m^3/kg)	Source
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 1 Max = 5	Based on Meijer (1995)	log-uniform	Min = 0.15 Max = 15.0	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.15 Max = 15.0	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	uniform	Min = 1 Max = 5	Based on Meijer (1995)	log-uniform	Min = 0.12 Max = 12.0	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	uniform	Min = 1 Max = 5	Based on Meijer (1995)	log-uniform	Min = 0.50 Max = 50.0	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 0.5	Based on Meijer (1995)	log-uniform	Min = 0.50 Max = 50.0	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	uniform	Min = 1 Max = 5	Based on Meijer (1995)	log-uniform	Min = 0.12 Max = 12.0	NRC (1995); Meijer (1990)
Element: **Se**						
Topopah Spring, welded (D)	exponential	Min = 0 Max = 0.03	Based on Meijer (1995)	log-uniform	Min = 2.6e−4 Max = 0.026	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	exponential	Min = 0 Max = 0.02	Based on Meijer (1995)	log-uniform	Min = 2.6e−4 Max = 0.026	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	exponential	Min = 0 Max = 0.02	Based on Meijer (1995)	log-uniform	Min = 3.0e−4 Max = 0.03	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	exponential	Min = 0 Max = 0.015	Based on Meijer (1995)	log-uniform	Min = 4.5e−4 Max = 0.045	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	exponential	Min = 0 Max = 0.03	Based on Meijer (1995)	log-uniform	Min = 2.5e−4 Max = 0.025	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	exponential	Min = 0 Max = 0.015	Based on Meijer (1995)	log-uniform	Min = 3.6e−4 Max = 0.036	NRC (1995); Meijer (1990)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

Hydrostratigraphy (Rock Type)	K_d Values					
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Bullfrog, nonwelded (Z)	exponential	Min = 0 Max = 0.015	Based on Meijer (1995)	log-uniform	Min = 0.0013 Max = 0.13	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	exponential	Min = 0 Max = 0.03	Based on Meijer (1995)	log-uniform	Min = 0.0013 Max = 0.13	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	exponential	Min = 0 Max = 0.015	Based on Meijer (1995)	log-uniform	Min = 3.6e−4 Max = 0.036	NRC (1995); Meijer (1990)
Element: **Sm**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	—	—	—
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	—	—	—
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	—	—	—
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	—	—	—
Element: **Sn**						

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

	K_d Values					
	TSPA-95 Values			**Proposed IPA Phase 3 Reference Values**		
Hydrostratigraphy (Rock Type)	**Distribution**	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Topopah Spring, welded (D)	uniform	Min = 0.02 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.0134 Max = 1.34	NRC (1995); Codell et al. (1992)
Topopah Spring, vitrophyre (V)	uniform	Min = 0.02 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.0134 Max = 1.34	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, vitric (V)	uniform	Min = 0.02 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.097 Max = 9.7	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.049 Max = 4.9	NRC (1995); Codell et al. (1992)
Prow Pass, welded (D)	uniform	Min = 0.02 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.034 Max = 3.4	NRC (1995); Codell et al. (1992)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.039 Max = 3.9	NRC (1995); Codell et al. (1992)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.035 Max = 3.5	NRC (1995); Codell et al. (1992)
Bullfrog, welded (D)	uniform	Min = 0.02 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.035 Max = 3.5	NRC (1995); Codell et al. (1992)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 0.3	Based on Meijer (1995)	log-uniform	Min = 0.039 Max = 3.9	NRC (1995); Codell et al. (1992)
Element: **Sr**						
Topopah Spring, welded (D)	uniform	*Unsat. Zone* Min = 0.01 Max = 0.05 *Sat. Zone* Min = 0.01 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.008 Max = 0.8	NRC (1995); Meijer (1990)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

	K_d Values					
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Topopah Spring, vitrophyre (V)	uniform	*Unsat. Zone* Min = 0 Max = 0.02 *Sat. Zone* Min = 0.02 Max = 0.05	Based on Meijer (1995)	log-uniform	Min = 0.008 Max = 0.8	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	uniform	*Unsat. Zone* Min = 0 Max = 0.02 *Sat. Zone* Min = 0.02 Max = 0.05	Based on Meijer (1995)	log-uniform	Min = 0.0034 Max = 0.34	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	*Unsat. Zone* Min = 0.5 Max = 2 *Sat. Zone* Min = 2.0 Max = 50	Based on Meijer (1995)	log-uniform	Min = 0.89 Max = 89.0	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	uniform	*Unsat. Zone* Min = 0.01 Max = 0.05 *Sat. Zone* Min = 0.01 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.045 Max = 4.5	NRC (1995); Meijer (1990)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Crater Flat, upper (Z)	uniform	*Unsat. Zone* Min = 0.5 Max = 2 *Sat. Zone* Min = 2.0 Max = 50	Based on Meijer (1995)	log-uniform	Min = 0.71 Max = 71.0	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	uniform	*Unsat. Zone* Min = 0.5 Max = 2 *Sat. Zone* Min = 2.0 Max = 50	Based on Meijer (1995)	log-uniform	Min = 0.028 Max = 2.8	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	uniform	*Unsat. Zone* Min = 0.01 Max = 0.05 *Sat. Zone* Min = 0.01 Max = 0.2	Based on Meijer (1995)	log-uniform	Min = 0.028 Max = 2.8	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	uniform	*Unsat. Zone* Min = 0.5 Max = 2 *Sat. Zone* Min = 2.0 Max = 50	Based on Meijer (1995)	log-uniform	Min = 0.71 Max = 71.0	NRC (1995); Meijer (1990)
Element: **Tc**						

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Topopah Spring, welded (D)	constant	0	Based on Meijer (1995)	log-uniform	Min = 1e−6 Max = 1e−4	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	constant	0	Based on Meijer (1995)	log-uniform	Min = 1e−6 Max = 1e−4	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, vitric (V)	constant	0	Based on Meijer (1995)	constant	0	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	constant	0	Based on Meijer (1995)	constant	0	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	constant	0	Based on Meijer (1995)	log-uniform	Min = 1.7e−5 Max = 1.7e−3	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	constant	0	Based on Meijer (1995)	constant	0	NRC (1995); Meijer (1990)
Bullfrog, nonwelded (Z)	constant	0	Based on Meijer (1995)	log-uniform	Min = 4.2e−4 Max = 0.042	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	constant	0	Based on Meijer (1995)	log-uniform	Min = 4.2e−4 Max = 0.042	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	constant	0	Based on Meijer (1995)	constant	0	NRC (1995); Meijer (1990)
Element: **Th**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.0048 Max = 0.48	NRC (1995); Codell et al. (1992)
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.0048 Max = 0.48	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.034 Max = 3.4	NRC (1995); Codell et al. (1992)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.017 Max = 1.7	NRC (1995); Codell et al. (1992)
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.012 Max = 1.2	NRC (1995); Codell et al. (1992)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.014 Max = 1.4	NRC (1995); Codell et al. (1992)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.013 Max = 1.3	NRC (1995); Codell et al. (1992)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.013 Max = 1.3	NRC (1995); Codell et al. (1992)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.014 Max = 1.4	NRC (1995); Codell et al. (1992)
Element: **U**						
Topopah Spring, welded (D)	beta	*Unsat. Zone* Min = 0 Max = 0.004 *Sat. Zone* Min = 0 Max = 0.005	Based on Meijer (1995)	log-uniform	Min = 2e−5 Max = 0.002	NRC (1995); Meijer (1990)
Topopah Spring, vitrophyre (V)	beta	*Unsat. Zone* Min = 0 Max = 0.003 *Sat. Zone* Min = 0 Max = 0.004	Based on Meijer (1995)	log-uniform	Min = 2e−5 Max = 0.002	NRC (1995); Meijer (1990)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Calico Hills/Prow Pass, vitric (V)	beta	*Unsat. Zone* Min = 0 Max = 0.003 *Sat. Zone* Min = 0 Max = 0.004	Based on Meijer (1995)	log-uniform	Min = 0.002 Max = 0.2	NRC (1995); Meijer (1990)
Calico Hills/Prow Pass, zeolitic (Z)	exponential	*Unsat. Zone* Min = 0 Max = 0.03 *Sat. Zone* Min = 0.005 Max = 0.02	Based on Meijer (1995)	log-uniform	Min = 1e−4 Max = 0.01	NRC (1995); Meijer (1990)
Prow Pass, welded (D)	beta	*Unsat. Zone* Min = 0 Max = 0.004 *Sat. Zone* Min = 0 Max = 0.005	Based on Meijer (1995)	constant	0	NRC (1995); Meijer (1990)
Crater Flat, upper (Z)	exponential	*Unsat. Zone* Min = 0 Max = 0.03 *Sat. Zone* Min = 0.005 Maz = 0.02	Based on Meijer (1995)	log-uniform	Min = 8e−5 Max = 0.008	NRC (1995); Meijer (1990)

Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
Hydrostratigraphy (Rock Type)	**TSPA-95 Values**			**Proposed IPA Phase 3 Reference Values**		
	Distribution	**Value (m^3/kg)**	**Source**	**Distribution**	**Value (m^3/kg)**	**Source**
Bullfrog, nonwelded (Z)	exponential	*Unsat. Zone* Min = 0 Max = 0.03 *Sat. Zone* Min = 0.005 Max = 0.02	Based on Meijer (1995)	log-uniform	Min = 2e−4 Max = 0.02	NRC (1995); Meijer (1990)
Bullfrog, welded (D)	beta	*Unsat. Zone* Min = 0 Max = 0.004 *Sat. Zone* Min = 0 Max = 0.005	Based on Meijer (1995)	log-uniform	Min = 2e−4 Max = 0.02	NRC (1995); Meijer (1990)
Crater Flat, middle (Z)	exponential	*Unsat. Zone* Min = 0 Max = 0.03 *Sat. Zone* Min = 0.005 Max 0.02	Based on Meijer (1995)	log-uniform	Min = 8e−5 Max = 0.008	NRC (1995); Meijer (1990)
Element:**Zr**						
Topopah Spring, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 4.8e−4 Max = 0.048	NRC (1995); Codell et al. (1992)
Topopah Spring, vitrophyre (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 4.8e−4 Max = 0.048	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, vitric (V)	beta	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.0034 Max = 0.34	NRC (1995); Codell et al. (1992)
Calico Hills/Prow Pass, zeolitic (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.0017 Max = 0.17	NRC (1995); Codell et al. (1992)

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Table 4-7. Listing of K_d values used in TSPA-95 and proposed to be used as the IPA Phase 3 reference parameter values (cont'd)

K_d Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Hydrostratigraphy (Rock Type)	Distribution	Value (m^3/kg)	Source	Distribution	Value (m^3/kg)	Source
Prow Pass, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.0012 Max = 0.12	NRC (1995); Codell et al. (1992)
Crater Flat, upper (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.0014 Max = 0.14	NRC (1995); Codell et al. (1992)
Bullfrog, nonwelded (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.0013 Max = 0.13	NRC (1995); Codell et al. (1992)
Bullfrog, welded (D)	uniform	Min = 0.1 Max = 2	Based on Meijer (1995)	log-uniform	Min = 0.0013 Max = 0.13	Wescott et al. (1995); Codell et al. (1992)
Crater Flat, middle (Z)	uniform	Min = 0.1 Max = 1	Based on Meijer (1995)	log-uniform	Min = 0.0014 Max = 0.14	NRC (1995); Codell et al. (1992)
Crater Flat, middle (Z)	constant	0	Based on Meijer (1995)	constant	0	NRC (1995); Codel et al. (1992)

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4.6.3 Comparison of the Saturated Zone Flow and Transport Input Parameter Values

The largest difference in the reference parameter values was the consideration of the length of the saturated zone. TSPA-95 used a constant total length of 5 km for all areas of the repository and did not divide it into separate hydrostratigraphies. The proposed IPA Phase 3 reference parameter values divides the saturated zone into different hydrostratigraphies and uses total lengths which range from 5.2 to 7.2 km for the 5 km boundary and lengths that range from 32.5 to 40.5 km for the 30 km boundary. The proposed IPA Phase 3 references parameter values utilizes a much smaller value for the saturated zone Darcy velocity than did TSPA-95. TSPA-95 used a log-normal distribution with a mean of 2.0 m/yr, a median of 1.0 m/yr, and a standard deviation of 0.486 m/yr for all subareas and legs of the saturated zone. The proposed IPA Phase 3 reference parameter values uses different constant values for each subarea and saturated zone leg which range from 0.26 to 0.85 m/yr. See table 4-8 for a listing of the values used in TSPA-95 and proposed to be used in IPA Phase 3.

4.7 GROUNDWATER DOSE ASSESSMENT—DCAGW MODULE OF TPA VERSION 3.1

4.7.1 Description of the Proposed IPA Phase 3 Model

The dose conversion analysis for groundwater module (DCAGW) calculates dose to individual receptors by multiplying the concentration of a given radionuclide in the groundwater by the appropriate dose conversion factor (DCF). There are three separate tables of DCFs used in the code, depending on the distance the receptor is located from the repository and the type of biosphere being evaluated (i.e., today's or pluvial). If the critical group is less than 20 km away from the repository, the DCFs are based solely on consumption of 2 L per day of contaminated water. DCFs for potential receptors located 20 km or greater from the repository take into account farming scenario pathways as described in LaPlante et al. (1995) including ingestion (of contaminated water, crops, and animal products), inhalation from resuspension, and direct exposure from immersion and ground shine. Pluvial climate DCFs are currently being developed and will be added to future TSPAs.

4.7.2 Description of the TSPA-95 Model

Doses to the receptor were calculated by assuming the individual was located on the surface of the earth above the plume centerline at 5 km from the repository outline. The concentration of each radionuclide in the groundwater was multiplied by the appropriate DCF for drinking water only (Eckerman et al., 1988) to obtain the annual dose from that radionuclide. The annual dose for the individual was calculated by summing the doses from all radionuclides.

Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3

SZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Variable	**Distribution**	**Parameter**	**Source**	**Distribution**	**Parameter**	**Source**
Longitudinal dispersivity for dilution calculations (m)	constant	50	Assumed in TRW Environmental Safety Systems, Inc. (1995)	log-normal	5 km Min = 0.3 Max = 30.0 30 km Min = 20 Max = 200	Assumed in NRC (1995); Assumed based on EPRI (1997)
Transverse dispersivity for dilution calculations (m)	constant	5	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	—
Line source length (km)	constant	4.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	—
Total saturated zone path length (km)	constant	5.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	5 km 30 km Subarea 1: 7.2 40.5 Subarea 2: 6.2 37.0 Subarea 3: 6.3 35.0 Subarea 4: 5.7 34.4 Subarea 5: 5.8 33.1 Subarea 6: 5.3 32.7 Subarea 7: 5.2 32.5	CNWRA staff best estimate

Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
	TSPA-95 Values			**Proposed IPA Phase 3 Reference Values**		
Variable	**Distribution**	**Parameter**	**Source**	**Distribution**	**Parameter**	**Source**
Saturated zone darcy velocity — subarea 1 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	TRW Environmental Safety Systems, Inc. (1995)	constant	undifferentiated Crater Flat (SCF): 0.74 Prow Pass unit (SPP): 0.63 Calico Hills unit (SCH): 0.42 Topopah Springs (STS): 0.44 SCH: 0.38 undifferentiated tuff aquifer (STFF): 0.38 transition zone of tuff and alluvial aquifer (STAC): 0.30 basin fill aquifer near Amargosa Valley (SAV): 0.26 basin fill aquifer — northern Amargosa farms (SUAF): 0.69 basin fill aquifer — southern Amargosa farms (SLAF): 0.63	CNWRA staff best estimate

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Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Variable	Distribution	Parameter	Source	Distribution	Parameter	Source
Saturated zone darcy velocity — subarea 2 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	Barr (1993)*	constant	SCF: 0.68 SPP: 0.62 SCH: 0.50 STS: 0.45 SCH: 0.42 STFF: 0.42 STAC: 0.29 SAV: 0.27 SUAF: 0.50 SLAF: 0.50	CNWRA staff best estimate
Saturated zone darcy velocity — subarea 3 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	Barr (1993)*	constant	SCF: 0.74 SPP: 0.62 SCH: 0.56 STS: 0.53 SCH: 0.50 STFF: 0.45 STAC: 0.33 SAV: 0.47 SUAF: 0.69 SLAF: 0.62	CNWRA staff best estimate

Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Variable	Distribution	Parameter	Source	Distribution	Parameter	Source
Saturated zone darcy velocity — subarea 4 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	Barr (1993)*	constant	SCF: 0.70 SPP: 0.62 SCH: 0.56 STS: 0.53 SCH: 0.50 STFF: 0.45 STAC: 0.33 SAV: 0.47 SUAF: 0.69 SLAF: 0.62	CNWRA staff best estimate
Saturated zone darcy velocity — subarea 5 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	Barr (1993)*	constant	Bullfrog unit (SBF): 0.85 SCF: 0.69 SPP: 0.61 SCH: 0.59 STS: 0.56 SCH: 0.51 STFF: 0.49 STAC: 0.39 SAV: 0.43 SUAF: 0.49 SLAF: 0.45	CNWRA staff best estimate

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Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
Variable	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameter	Source	Distribution	Parameter	Source
Saturated zone darcy velocity — subarea 6 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	Barr (1993)*	constant	SCF: 0.68 SPP: 0.61 SCH: 0.59 STS: 0.56 SCH: 0.51 STFF: 0.49 STAC: 0.39 SAV: 0.43 SUAF: 0.49 SLAF: 0.45	CNWRA staff best estimate
Saturated zone darcy velocity — subarea 7 (m/yr)	log-normal	Mean = 2.0 Median = 1.0 STD = 0.4859	Barr (1993)*	constant	SCF: 0.65 SPP: 0.61 SCH: 0.59 STS: 0.56 SCH: 0.51 STFF: 0.49 STAC: 0.39 SAV: 0.43 SUAF: 0.49 SLAF: 0.45	CNWRA staff best estimate
Repository width (km)	constant	4.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	3.6	CNWRA staff best estimate

Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Variable	Distribution	Parameter	Source	Distribution	Parameter	Source
Screened interval depth (m)	constant	50.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	—
Discharge area (m^2)	(width and depth used, see above for area)	2.0e5	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	Wescott et al. (1995)
Fracture Beta	—	—		uniform (all areas)	Min = 1.45 Max = 12.3	CNWRA staff best estimate
Well pumping rate at 30 km critical group (gal/day)	—	—		uniform	Min = 1.0e6 Max = 8.0e6	Assumed based on Wescott et al. (1995)
Saturated zone path length — subarea 1 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SCF: 470 SPP: 700 SCH: 1300 STS: 300 SCH: 280 STFF: 3020 STAC: 15100 SAV: 15000 SUAF: 7400 SLAF: 9400	CNWRA staff best estimate

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Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
Variable	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameter	Source	Distribution	Parameter	Source
Saturated zone path length — subarea 2 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SCF: 340 SPP: 250 SCH: 1200 STS: 230 SCH: 500 STFF: 2390 STAC: 14750 SAV: 12700 SUAF: 8300 SLAF: 8900	CNWRA staff best estimate
Saturated zone path length — subarea 3 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SCF: 1000 SPP: 380 SCH: 890 STS: 380 SCH: 600 STFF: 1850 STAC: 14700 SAV: 10000 SUAF: 9200 SLAF: 8500	CNWRA staff best estimate

Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
Variable	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameter	Source	Distribution	Parameter	Source
Saturated zone path length — subarea 4 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SCF: 360 SPP: 380 SCH: 890 STS: 380 SCH: 600 STFF: 1850 STAC: 14700 SAV: 10000 SUAF: 9200 SLAF: 8500	CNWRA staff best estimate
Saturated zone path length — subarea 5 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SBF: 150 SCF: 1500 SPP: 360 SCH: 470 STS: 190 SPP: 450 SCH: 800 STFF: 1040 STAC: 12950 SAV: 9300 SUAF: 10200 SLAF: 8400	CNWRA staff best estimate

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Table 4-8. Comparison of the reference parameter values for the saturated zone flow and transport module used in TSPA-95 and proposed to be used in IPA Phase 3 (cont'd)

SZFT Input Values						
Variable	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameter	Source	Distribution	Parameter	Source
Saturated zone path length — subarea 6 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SCF: 1200 SPP: 360 SCH: 470 STS: 190 SPP: 450 SCH: 800 STFF: 1040 STAC: 12950 SAV: 9300 SUAF: 10200 SLAF: 8400	CNWRA staff best estimate
Saturated zone path length — subarea 7 (m)	constant	5000	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	SCF: 1000 SPP: 360 SCH: 470 STS: 190 SPP: 450 SCH: 800 STFF: 1040 STAC: 12950 SAV: 9300 SUAF: 10200 SLAF: 8400	CNWRA staff best estimate

* Barr, G.E. 1993. Personal Communication.

4.7.3 Comparison of the Dose Conversion Analysis for Groundwater Input Parameter Values

As can be seen in table 4-9, the assumptions made by TSPA-95 and proposed for IPA Phase 3 about the receptor are similar. Both assumed that the receptor individual ingests 2 L of water per day. The proposed IPA Phase 3 model and TSPA-95 both consider a receptor individual located 5 km away from the repository, however, the proposed IPA Phase 3 model also considers a receptor individual located 30 km from the repository. A receptor located at 5 km from the repository is assumed to receive dose solely from drinking water consumption in both codes. In the proposed IPA Phase 3 model, however, the receptor individual at 30 km is assumed to be an Amargosa Desert farmer/rancher who uses groundwater for all water needs including drinking, crop irrigation, and nourishing livestock resulting in a different DCF.

Since TSPA-95 and the proposed IPA Phase 3 reference parameter values use the same source for ingestion DCFs (Eckerman, 1988), there is agreement between the two documents for doses computed by assuming 2 L per day of water consumption and current climatic conditions. DCFs for pluvial conditions are being developed and will be included in later TSPAs. Two radionuclides, ^{135}Cs and ^{238}Pn, have significant differences between TSPA-95 and the proposed IPA Phase 3 reference parameter values due to errors in the TSPA-95 document. The errors can be confirmed by returning to the Eckerman et al. (1988) source and converting those values to the proper units. For cesium-135, the value of 5.85e6 rem-m^3/g-yr in TSPA-95 should be reduced by about six orders of magnitude to 5.93e0 to correctly reflect the data in the EPA document. This converts to 5.16e3 rem-m^3/Ci-yr, which is the value proposed for the IPA Phase 3 reference parameter values. The drinking water DCF for plutonium-238 in TSPA-95 should be increased from 3.03e6 rem-m^3/g-yr to 3.99e7 rem-m^3/g-yr to correspond to the EPA data. This converts to 2.34e6 rem-m^3/Ci-yr which is also the value proposed for the IPA Phase 3 reference parameter values. Comparison of the DCFs from drinking water only used in TSPA-95 and proposed to be used in IPA Phase 3 can be seen in table 4-10.

When the receptor individual was more than 20 km from the repository, the proposed IPA Phase 3 model uses DCFs that take into account the dose received from all pathways, not just drinking water. The groundwater DCFs proposed to be used in IPA Phase 3 are listed in table 4-11.

4.8 CLIMATE CHANGE—CLIMATO MODULE OF TPA VERSION 3.1

4.8.1 Description of the Proposed IPA Phase 3 Model

The climate change (CLIMATO) module analyzes effects of climate change on release and transport of radionuclides from the repository. A time-series process is used to generate a climatic record with deterministic climate variation sequence and regularly spaced perturbations (e.g., changes from century to century). An input file specifying functions of full-glacial MAP and MAT at particular points in the future is supplied, with enough points to define climatic variation. Linear interpolation of the statistical parameters is used to define the parameters at intermediate times. A correlation parameter is sampled from a specified distribution in the code to determine the correlation between temperature and annual precipitation.

Table 4-9. Listing of the reference parameter values for the dose assessment from groundwater module used in TSPA-95 and proposed to be the reference parameter values in IPA Phase 3

DCAGW Input Parameters						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Source	Distribution	Value	Source
Distance to critical group (km)	constant	5	Assumed in TSPA-95	constants	5 30	Assumed in TSPA-95 Assumed in Baca et al. (1996)
Ingestion rate of water of receptor individual at 5 km (used to calculate DCFs)(L/day)	constant	2	10 CFR 191	constants	2	10 CFR 191
Intake from all pathways of water of receptor individual at 20 km (used to calculate DCFs) (L/yr)	—	—	—	lognormal	Min = 113 Max = 1,081	Roseburry and Burmaster (1992)

Table 4-10. Listing of dose conversion factors for drinking water only used in TSPA-95 and proposed to be used as the reference values in IPA Phase 3 (base climate)

Dose Conversion Factors — Drinking Water Only Pathway (Base Climate)						
TSPA-95 Values				Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (rem/yr) / (Ci/m³)	Source	Distribution	Value (rem/yr) / (Ci/m³)	Source
U-238	constant	1.83e5	Eckerman et al. (1988)	constant	1.86e5	Eckerman et al. (1988)
Cm-246	constant	2.67e6	Eckerman et al. (1988)	constant	2.70e6	Eckerman et al. (1988)
Cm-245	constant	2.69e6	Eckerman et al. (1988)	constant	2.73e6	Eckerman et al. (1988)
Am-242m	constant	2.53e6	Eckerman et al. (1988)	constant	2.57e6	Eckerman et al. (1988)
Pu-238	constant	1.77e5	Eckerman et al. (1988)	constant	2.34e6	Eckerman et al. (1988)
U-234	constant	2.03e5	Eckerman et al. (1988)	constant	2.07e5	Eckerman et al. (1988)
Th-230	constant	3.96e5	Eckerman et al. (1988)	constant	4.00e5	Eckerman et al. (1988)
Ra-226	constant	9.53e5	Eckerman et al. (1988)	constant	9.67e5	Eckerman et al. (1988)
Pb-210	constant	3.86e6	Eckerman et al. (1988)	constant	3.91e6	Eckerman et al. (1988)
Cm-243	—	—	—	constant	1.83e6	Eckerman et al. (1988)
Am-243	constant	2.61e6	Eckerman et al. (1988)	constant	2.64e6	Eckerman et al. (1988)
Pu-239	constant	2.54e6	Eckerman et al. (1988)	constant	2.58e6	Eckerman et al. (1988)
U-235	constant	1.92e5	Eckerman et al. (1988)	constant	1.94e5	Eckerman et al. (1988)
Pa-231	constant	7.61e6	Eckerman et al. (1988)	constant	7.72e6	Eckerman et al. (1988)
Ac-227	constant	1.02e7	Eckerman et al. (1988)	constant	1.03e7	Eckerman et al. (1988)
Cm-245	constant	2.69e6	Eckerman et al. (1988)	constant	2.73e6	Eckerman et al. (1988)
Pu-241	constant	4.93e4	Eckerman et al. (1988)	constant	5.00e4	Eckerman et al. (1988)
Am-241	constant	2.62e6	Eckerman et al. (1988)	constant	2.66e6	Eckerman et al. (1988)
Np-237	constant	3.19e6	Eckerman et al. (1988)	constant	3.24e6	Eckerman et al. (1988)
U-233	constant	2.08e5	Eckerman et al. (1988)	constant	2.11e5	Eckerman et al. (1988)
Th-229	constant	2.54e6	Eckerman et al. (1988)	constant	2.58e6	Eckerman et al. (1988)

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Table 4-10. Listing of dose conversion factors for drinking water only used in TSPA-95 and proposed to be used as the reference values in IPA Phase 3 (base climate) (cont'd)

Dose Conversion Factors — Drinking Water Only Pathway (Base Climate)							
	TSPA-95 Values				Proposed IPA Phase 3 Reference Values		
Element	**Distribution**	**Value (rem/yr)/(Ci/m^3)**	**Source**	**Distribution**	**Value (rem/yr)/(Ci/m^3)**	**Source**
Cm-244	constant	1.45e6	Eckerman et al. (1988)	constant	1.47e6	Eckerman et al. (1988)
Pu-240	constant	2.54e6	Eckerman et al. (1988)	constant	2.58e6	Eckerman et al. (1988)
U-236	constant	1.93e5	Eckerman et al. (1988)	constant	1.96e5	Eckerman et al. (1988)
U-232	—	—	—	constant	9.56e5	Eckerman et al. (1988)
Sm-151	constant	2.79e2	Eckerman et al. (1988)	constant	2.84e2	Eckerman et al. (1988)
Cs-137	—	—	—	constant	3.65e4	Eckerman et al. (1988)
Cs-135	constant	5.09e9	Eckerman et al. (1988)	constant	5.16e3	Eckerman et al. (1988)
I-129	constant	1.99e5	Eckerman et al. (1988)	constant	2.01e5	Eckerman et al. (1988)
Sn-126	constant	1.40e4	Eckerman et al. (1988)	constant	1.42e4	Eckerman et al. (1988)
Sn-121m	—	—	—	constant	1.13e3	Eckerman et al. (1988)
Ag-108m	—	—	—	constant	5.56e3	Eckerman et al. (1988)
Pd-107	constant	1.08e2	Eckerman et al. (1988)	constant	1.09e2	Eckerman et al. (1988)
Tc-99	constant	1.05e3	Eckerman et al. (1988)	constant	1.07e3	Eckerman et al. (1988)
Mo-93	—	—	—	constant	9.83e2	Eckerman et al. (1988)
Nb-94	constant	5.13e3	Eckerman et al. (1988)	constant	5.21e3	Eckerman et al. (1988)
Zr-93	constant	1.20e3	Eckerman et al. (1988)	constant	1.21e3	Eckerman et al. (1988)
Sr-90	—	—	—	constant	1.21e3	Eckerman et al. (1988)
Se-79	constant	6.26e3	Eckerman et al. (1988)	constant	6.35e3	Eckerman et al. (1988)
Ni-63	constant	4.16e2	Eckerman et al. (1988)	constant	4.21e2	Eckerman et al. (1988)
Ni-59	constant	1.50e2	Eckerman et al. (1988)	constant	1.53e2	Eckerman et al. (1988)
Cl-36	constant	2.18e3	Eckerman et al. (1988)	constant	2.21e3	Eckerman et al. (1988)

Table 4-10. Listing of dose conversion factors for drinking water only used in TSPA-95 and proposed to be used as the reference values in IPA Phase 3 (base climate) (cont'd)

Dose Conversion Factors — Drinking Water Only Pathway (Base Climate)						
TSPA-95 Values				Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (rem/yr)/(Ci/m^3)	Source	Distribution	Value (rem/yr)/(Ci/m^3)	Source
C-14	constant	1.47e3	Eckerman et al. (1988)	constant	1.52e3	Eckerman et al. (1988)
Nb-93m	constant	3.78e2	Eckerman et al. (1988)	—	—	—
Ra-228	constant	1.03e6	Eckerman et al. (1988)	—	—	—
Th-232	constant	1.96e6	Eckerman et al. (1988)	—	—	—

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Table 4-11. Listing of the dose conversion factors for all pathways proposed to be used as reference values in IPA Phase 3 (base climate)

Dose Conversion Factors — All Pathways (Base Climate)						
TSPA-95 Values				Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (rem/yr) (Ci/m3)	Source	Distribution	Value (rem/yr) (Ci/m3)	Source
U-238	—	—	—	constant	7.2e4	LaPlante et al. (1995)
Cm-246	—	—	—	constant	8.1e6	LaPlante et al. (1995)
Pu-242	—	—	—	constant	1.0e5	LaPlante et al. (1995)
Am-242m	—	—	—	constant	7.6e6	LaPlante et al. (1995)
Pu-238	—	—	—	constant	0	LaPlante et al. (1995)
U-234	—	—	—	constant	6.0e4	LaPlante et al. (1995)
Th-230	—	—	—	constant	1.2e6	LaPlante et al. (1995)
Ra-226	—	—	—	constant	2.8e6	LaPlante et al. (1995)
Pb-210	—	—	—	constant	1.3e7	LaPlante et al. (1995)
Cm-243	—	—	—	constant	5.4e6	LaPlante et al. (1995)
Am-243	—	—	—	constant	7.9e6	LaPlante et al. (1995)
Pu-239	—	—	—	constant	1.1e5	LaPlante et al. (1995)
U-235	—	—	—	constant	8.4e4	LaPlante et al. (1995)
Pa-231	—	—	—	constant	2.3e7	LaPlante et al. (1995)
Ac-227	—	—	—	constant	3.1e7	LaPlante et al. (1995)
Cm-245	—	—	—	constant	8.1e6	LaPlante et al. (1995)
Pu-241	—	—	—	constant	3.2e3	LaPlante et al. (1995)
Am-241	—	—	—	constant	7.9e6	LaPlante et al. (1995)
Np-237	—	—	—	constant	1.3e7	LaPlante et al. (1995)
U-233	—	—	—	constant	6.1e4	LaPlante et al. (1995)
Th-229	—	—	—	constant	8.1e6	LaPlante et al. (1995)
Cm-244	—	—	—	constant	4.3e6	LaPlante et al. (1995)

Table 4-11. Listing of the dose conversion factors for all pathways proposed to be used as reference values in IPA Phase 3 (base climate) (cont'd)

Dose Conversion Factors — All Pathways (Base Climate)							
TSPA-95 Values				Proposed IPA Phase 3 Reference Values			
Element	Distribution	Value (rem/yr) (Ci/m3)	Source	Distribution	Value (rem/yr) (Ci/m3)	Source	
Pu-240	—	—	—	constant	1.1e5	LaPlante et al. (1995)	
U-236	—	—	—	constant	5.7e4	LaPlante et al. (1995)	
U-232	—	—	—	constant	2.4e5	LaPlante et al. (1995)	
Sm-151	—	—	—	constant	1.2e3	LaPlante et al. (1995)	
Cs-137	—	—	—	constant	7.6e5	LaPlante et al. (1995)	
Cs-135	—	—	—	constant	1.0e5	LaPlante et al. (1995)	
I-129	—	—	—	constant	3.1e6	LaPlante et al. (1995)	
Sn-126	—	—	—	constant	6.3e5	LaPlante et al. (1995)	
Sn-121m	—	—	—	constant	4.3e4	LaPlante et al. (1995)	
Ag-108m	—	—	—	constant	0	LaPlante et al. (1995)	
Pd-107	—	—	—	constant	8.1e2	LaPlante et al. (1995)	
Tc-99	—	—	—	constant	8.4e3	LaPlante et al. (1995)	
Mo-93	—	—	—	constant	4.4e3	LaPlante et al. (1995)	
Nb-94	—	—	—	constant	2.0e5	LaPlante et al. (1995)	
Zr-93	—	—	—	constant	3.5e3	LaPlante et al. (1995)	
Sr-90	—	—	—	constant	6.1e5	LaPlante et al. (1995)	
Se-79	—	—	—	constant	5.3e4	LaPlante et al. (1995)	
Ni-63	—	—	—	constant	3.8e3	LaPlante et al. (1995)	
Ni-59	—	—	—	constant	1.4e3	LaPlante et al. (1995)	
Cl-36	—	—	—	constant	8.7e4	LaPlante et al. (1995)	
C-14	—	—	—	constant	1.9e4	LaPlante et al. (1995)	

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4.8.2 Description of the TSPA-95 Model

Climate change could change several key parameters in the performance analysis: the infiltration rate, the groundwater level, and the dripping flow on the WP. To account for this effect, a combination of a random function and a function that varies periodically with time were used. For the change in infiltration rate and dripping flow rate, the product of these functions was added to one and that sum was multiplied by the base rate. To calculate the rise of the water table, two similar functions were multiplied together and the product was added to the current water table elevation to find the new water table elevation.

4.8.3 Comparison of the Climate Change Input Parameter Values

Because TSPA-95 calculated the effect of climate change in a different manner than the proposed IPA Phase 3 model, it is not possible to compare the input parameters into the code. The range of net effects of climate change on the water table elevation can be compared. As can be seen in table 4-12, the ranges of possible effects on the rise of the water table in TSPA-95 are very similar to the proposed IPA Phase 3 model. No other parameters are directly comparable, although the MAP multiplier in the proposed IPA Phase 3 reference parameter values is related to the infiltration rate multiplier in TSPA-95. TSPA-95 used a slightly more conservative range of 1 to 5 for this parameter, while the proposed IPA Phase 3 reference parameter value is a range of 1.5 to 2.5.

4.9 SEISMIC EVENTS—SEISMO MODULE OF TPA VERSION 3.1

4.9.1 Description of the Proposed IPA Phase 3 Model

The seismic events (SEISMO) module calculates WP disruptions caused by repeated seismic motion. The module predicts seismic events that lead to rock fall onto WPs, which causes stress and deformation of the WP. SEISMO estimates effects from comparatively small-magnitude repeated seismic motions and less frequent large-magnitude earthquakes. The frequency of seismic events is given by a seismic hazard curve which gives the annual probability for events larger than a given magnitude. Using this seismic history, SEISMO determines effects on WPs emplaced in the drift assuming

- Emplacement drift is unbackfilled
- Dynamic vibration of the WP and its support system is negligible
- Thermally weakened rocks of the emplacement drift roof, once loosened by seismic shaking, fall due only to gravity
- Surface of the rock falling on the WP is flat

Table 4-12. Comparison of the climate change reference parameter values used in TSPA-95 and proposed to be used in the IPA Phase 3 reference data set

CLIMATO Input Values						
Variable	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameters	Source	Distribution	Parameters	Source
Time function of infiltration rate and dripping flow multiplier	triangular wave	Min = 0 at 0 and 100,000 yr Max = 1 at 50,000 yr Period = 100,000 yr	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	—
Random number multiplier to calculate infiltration rate multiplier, rise in water table, and dripping flow multiplier due to climate change	uniform	Min = 0 Max = 4.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	—
Rise in water table elevation due to climate change (m)	(function of time and random multiplier)	Min = 0 Max = 80.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	constant	*Base Case* 0 (no change) *Pluvial Case* 100	Wescott et al. (1995)
Mean average precipitation (MAP) multiplier at glacial maximum	—	—	—	uniform	Min = 1.5 Max = 2.5	Assumed based on Stothoff (1997)
Mean average infiltration multiplier at glacial maximum	(function of time and random multiplier)	Min = 1.0 Max = 5.0	Assumed in TRW Environmental Safety Systems, Inc. (1995)	—	—	
Mean average temperature (MAT) increase at glacial maximum (°C)	—	—	—	uniform	Min = −10 Max = −5	Assumed based on Stothoff (1997)
Standard deviation of MAP about mean in one time period (mm/yr)	—	—	—	constant	10	Assumed based on Stothoff (1997)

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Table 4-12. Comparison of the climate change reference parameter values used in TSPA-95 and proposed to be used in the IPA Phase 3 reference data set (cont'd)

CLIMATO Input Values						
Variable	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Parameters	Source	Distribution	Parameters	Source
Standard deviation of MAT about mean in one time period (°C)	—	—	—	constant	1	Assumed based on Stothoff (1997)
Correlation between MAP and MAT	—	—	—	constant	−0.8	Assumed based on Stothoff (1997)

The impact force of the rock falling and striking the WP is approximated using the principle of conservation of energy assuming (Popov, 1970)

- WPs can be treated as equivalent linear elastic springs with a spring constant k
- No energy dissipation takes place at the point of impact due to local inelastic deformation of the WP material
- Deformation of WPs is directly proportional to magnitude of the impact force
- Inertia of the WP resisting an impact may be neglected

The weight of the rock falling on the WP is estimated from the results of a drift stability analysis using the computer code Universal Distinct Element Code (UDEC) (Itasca Consulting Group, Inc. 1996).

4.9.2 Description of the TSPA-95 Model

TSPA-95 cited the papers by Gauthier et al. (1995) and Wilson et al. (1994) and assumed that the effects of potential seismic activity on the repository were negligible, so these effects were not considered further.

4.9.3 Comparison of the Seismic Events Input Parameter Values

Since TSPA-95 did not consider seismic effects, a comparison between the reference parameter values is not possible. Values proposed for IPA Phase 3 reference values are listed in table 4-13.

4.10 VOLCANIC EVENTS—VOLCANO MODULE OF TPA VERSION 3.1

4.10.1 Description of the Proposed IPA Phase 3 Model

The volcanic event (VOLCANO) module provides an estimate of the amount of waste entrained during a volcanic eruption and available for transport to the surface together with the number of WPs that are damaged by a volcanic dike. This estimate is based on (i) probability of volcanic eruptions within a subregion encompassing the proposed repository, (ii) dike length and orientation, (iii) area disrupted during flow of magma through a conduit, and (iv) distribution of WPs in the repository. The VOLCANO module uses sampled parameters to simulate the locations and characteristics of volcanic events within a user-defined region that includes the repository. The primary hazard associated with volcanism in the YM region is related to formation of a new volcanic center rather than reactivation of a pre-existing volcanic center. It is assumed that only a single dike occurs during the volcanic event and the probability of an igneous event is the probability that the center of this dike will fall within the user-defined region. Extrusive events (volcanic events that form both a dike and a core) have the potential to fail WPs and create an airborne release of radionuclides, whereas intrusive events (volcanic events that only form dikes) have the potential to fail WPs. Secondary effects of volcanism, such as disruption of canisters in sections of the dike far from the conduit, additional thermal loading on canisters due to dike injection, and changes in the level of the groundwater due to dike injection, are not considered. Monte Carlo sampling is used to generate the location of the center of the dike and the conduit in the rectangular

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Table 4-13. Listing of the reference parameter values for the seismic events module proposed to be used in IPA Phase 3

SEISMO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Variable	Distribution	Parameter	Source	Distribution	Parameter	Source
Modulus of elasticity of package material (N/m^2)	—	—	—	constant	2.069e11	Assumed in Wescott et al. (1995)
Weight percentage of rockfall that hits WP	—	—	—	constant	1.00	CNWRA staff best estimate
Weight of WP (N)	—	—	—	constant	1.27e5	CRWMS (1996)
WP stiffness (Pa-m)	—	—	—	constant	4.1274e9	CNWRA staff best estimate
Rock modulus of elasticity (Pa)	—	—	—	constant	3.448e10	Brechel et al. (1995)
WP Poisson ratio	—	—	—	constant	0.2	CNWRA staff best estimate
Rock Poisson ratio	—	—	—	constant	0.3	CNWRA staff best estimate
Rock falling distance (m)	—	—	—	constant	2.0	CNWRA staff best estimate
Waste package falling distance (m)	—	—	—	constant	0.3	CNWRA staff best estimate
Return period for 0.25 g seismic event (yr)	—	—	—	constant	1000	OCRWM (1995)
Return period for 0.4 g seismic event (yr)	—	—	—	constant	2500	OCRWM (1995)
Return period for 0.5 g seismic event (yr)	—	—	—	constant	4000	OCRWM (1995)
Return period for 0.7 g seismic event (yr)	—	—	—	constant	16000	OCRWM (1995)
Return period for 0.9 g seismic event (yr)	—	—	—	constant	30000	OCRWM (1995)
Return period for 1.0 g seismic event (yr)	—	—	—	constant	50000	OCRWM (1995)

region surrounding the repository horizon. Estimates of the repository area impacted by a dike and the conduit are calculated to enable calculation of the number of WPs and quantities of radionuclides available for transport in the conduit from the initial inventory of the repository.

4.10.2 Description of the TSPA-95 Model

Although no analysis of the effects of volcanic disruption or the repository were carried out in TSPA-95, the following methodology for completing the analysis was described. Spatial simulation modeling was conducted using the FRACMAN computer code to estimate the probability of magmatic disruption for specific areas associated with the YM site. The simulation uses the set of alternative spatial and structural models described in the volcanism status report (Crowe et al., 1995). For each spatial and structural model, simulations have been run using three sets of feeder systems for basaltic volcanic centers: (i) simple linear feeder dikes, (ii) linear feeder dikes with associated plug-like intrusive masses, and (iii) linear feeder dikes with associated plugs and sill-like intrusions. Dimensions of the basalt feeder systems have been developed from literature references and analog studies of eroded basalt centers. Orientations of the basalt feeder systems were established using constraints from the local stress field, orientations of basalt centers and cone alignments, and predicts/observations of the spatial geometry imposed by individual spatial or structural models. Data from simulations have been used to refine the disruption of the repository and associated areas. These data will be used to revise the probabilistic-volcanic-hazard assessments of Crowe et al. (1995). A second application of the results from simulation modeling would be input for studies of the subsurface effects of magmatic disruption of the potential repository.

4.10.3 Comparison of the Volcanic Proposed IPA Phase 3 Model

Since an analysis of a volcanic scenario was not completed in TSPA-95, no comparison can be done between the TSPA-95 values and the proposed IPA Phase 3 reference values. Values proposed for the IPA Phase 3 base case are listed in table 4-14.

4.11 VOLCANIC ASHPLUME DISPERSION—ASHPLUMO MODULE OF TPA VERSION 3.1

4.11.1 Description of the Proposed IPA Phase 3 Model

The volcanic ashplume dispersion (ASHPLUMO) module calculates the areal density of ash and incorporated SF at points on the surface of the earth after an extrusive volcanic event penetrates the repository and exhumes SF. Using published data for wind velocity at the YM site and the estimate of pertinent volcanic parameters of events similar to those that may have occurred at the YM site in the past, the ASHPLUMO module simulates the transport of contaminated particles (composed of SF and ash) to surface points downwind. The exposure scenario can be divided into four subprocesses. First, the magma enters the repository and becomes contaminated with SF particles. Second, tephra forms from the magma and SF is incorporated into tephra (Jarzemba and LaPlante, 1996). Third, the eruption column and contaminant plume form and produce fallout at various distances downwind from the volcano (Suzuki, 1983; Jarzemba, 1996). Fourth, radionuclide concentrations cause doses to be incurred at a receptor location. It is assumed that the ash particles from the eruption are the carriers of the radionuclides. The ASHPLUMO module uses the model described in Suzuki (1983) that relates eruption magnitude to ash distribution, which is modified to relate eruption magnitude to SF distribution for YM.

Table 4-14. Listing of the reference parameter values for volcanic events module proposed to be used in IPA Phase 3

VOLCANO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Source	Distribution	Value	Source
Time of next volcanic event (yr)	—	—	—	uniform	Min = 1.0e2 Max = 1.0e4	time period of interest
Annual probability of volcanic event	—	—	—	constant	Min = 1.0e−8 Max = 1.0e−7	Hill et al. (1996)
Fraction of extrusive volcanic events	—	—	—	constant	0.999	Set to ensure that all events have a cone formation
Dike angle (degrees)	—	—	—	uniform	Min = 0.0 Max = 15.0	Morris et al. (1996)
Dike length (m)	—	—	—	uniform	Min = 2.0e3 Max = 8.0e3	Delaney and Gartner (1995)
Dike width (m)	—	—	—	uniform	Min = 1.0 Max = 10.0	Delaney and Gartner (1995)
Cone diameter (m)	—	—	—	uniform	Min = 10.0 Max = 50.0	Hill (1996)

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4.11.2 Description of the TSPA-95 Model

Since TSPA-95 did not include volcanic scenarios, the release of SF via a volcanic eruption was not modeled.

4.11.3 Comparison of the Ashplume Dispersion Input Parameter Values

Because TSPA-95 did not model the dispersion of ash, a comparison of the initial parameter values between the two codes is not possible. A listing of the parameters proposed for the IPA Phase 3 base case is shown in table 4-15.

4.12 VOLCANIC ASH BLANKET REMOVAL—ASHRMOVO MODULE OF TPA VERSION 3.1

4.12.1 Description of the Proposed IPA Phase 3 Model

The volcanic ash blanket removal (ASHRMOVO) module calculates the time-dependent radionuclide areal densities of contaminated soil surface layers subject to removal by leaching, erosion, and radioactive decay. It provides generalized analytical solutions to calculate dynamic serial radioactive decay, including nonradioactive decay losses by leaching or erosion. The leach rate of a given radionuclide is limited by the solubility limit of the radionuclide and the amount of radionuclide present. The K_ds used in ASHRMOVO will not necessarily match the values in the UZFT module because of differences in the materials through which radioactive particles are being transported. The solubilities used in ASHRMOVO may not match the values used in EBSFAIL because of differences in the environment, such as the pH and oxygen content of the water contacting the ash blanket.

4.12.2 Description of TSPA-95 Model

Since TSPA-95 did not include volcanic scenarios, the release of SF via a volcanic eruption was not modeled.

4.12.3 Comparison of the Ash Removal Input Parameter Values

Since TSPA-95 did not model ash removal, a comparison of the input parameter values is not possible. A listing of the values used in the proposed for the IPA Phase 3 reference parameter values can be seen in table 4-16.

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Table 4-15. Listing of the reference parameter values for the volcanic ashplume dispersion module proposed to be used in IPA Phase 3

ASHPLUMO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Source	Distribution	Value	Source
Eruption duration (s)	—	—	—	log-uniform	Min = 6.31e4 Max = 7.24e6	Assumed in Jarzemba et al. (1997)
Beta	—	—	—	log-uniform	Min = 0.01 Max = 0.5	Assumed based on Suzuki (1983)
Mean ash particle size (cm)	—	—	—	log-triangular	Min = 0.01 Peak = 0.1 Max = 10.0	Assumed in Jarzemba et al. (1997)
Standard deviation for log of particle size	—	—	—	log-uniform	Min = 0.1 Max = 2.0	Assumed in Jarzemba et al. (1997)
Incorporation ratio	—	—	—	constant	0.3	Assumed in Jarzemba et al. (1997)
Wind direction from due east (degrees)	—	—	—	uniform	Min = −180.0 Max = 180.0	Assumed
Minimum ash density (g/cm^3)	—	—	—	constant	0.8	Assumed based on Suzuki (1983)
Maximum ash density (g/cm^3)	—	—	—	constant	2.5	Assumed based on Suzuki (1983)
Minimum value of ash log-diameter	—	—	—	constant	−2.0	Assumed in Jarzemba et al. (1997)
Ash particle size distribution standard deviation	—	—	—	log-uniform	Min = 0.1 Max = 1.0	Assumed in Jarzemba et al. (1997)
Maximum value of ash log-diameter	—	—	—	constant	−1.0	Assumed in Jarzemba et al. (1997)

Table 4-15. Listing of the reference parameter values for the volcanic ashplume dispersion module proposed to be used in IPA Phase 3 (cont'd)

ASHPLUMO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Source	Distribution	Value	Source
Particle shape factor	—	—	—	constant	0.5	Assumed based on Suzuki (1983)
Air density (g/cm^3)	—	—	—	constant	1.29e−3	Sears et al. (1983)
Air viscosity (g/cm/s)	—	—	—	constant	1.8e−4	Sears et al. (1983)
Constant relating eddy diffusion to particle fall time ($cm^2/s^{5/2}$)	—	—	—	constant	4.0e2	Suzuki (1983)
Maximum particle diameter for transport (cm)	—	—	—	constant	10.0	Assumed in Jarzemba et al. (1997)
Fuel particle diameter (cm)	—	—	—	log-triangular	Min = 0.01 Max = 1.0 Peak = 0.1	Assumed in Jarzemba et al. (1997)
Minimum height of eruption column for integration (km)	—	—	—	constant	1.0e−3	Assumed in Jarzemba et al. (1997)
Threshold limit for ash accumulation (g/cm^2)	—	—	—	constant	1.0e−10	Assumed in Jarzemba et al. (1997)
Incorporable fuel size ratio	—	—	—	constant	1.0	Assumed in Jarzemba et al. (1997)
Wind speed (cm/sec)	—	—	—	exponential	Lambda = 0.002	CNWRA staff best estimate
Event power (W)	—	—	—	log-uniform	Min = 2.57e9 Max = 3.55e11	Assumed in Jarzemba et al. (1997)
Minimum fuel particle diameter (cm)	—	—	—	constant	1.0e−4	CNWRA staff best estimate

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Table 4-15. Listing of the reference parameter values for the volcanic ashplume dispersion module proposed to be used in IPA Phase 3 (cont'd)

ASHPLUMO Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Source	Distribution	Value	Source
Mode fuel particle diameter (cm)	—	—	—	constant	1.0e−3	CNWRA staff best estimate
Maximum fuel particle diameter (cm)	—	—	—	constant	1.0e−2	CNWRA staff best estimate

Table 4-16. Listing of the reference parameter values for the volcanic ash blanket removal module proposed to be used in IPA Phase 3

ASHRMOVO Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Source	Distribution	Value	Source
Annual precipitation rate (m/yr)	—	—	—	constant	0.15	Wilson et al. (1994)
Fraction of precipitation lost to evapotranspiration	—	—	—	constant	0.68	Assumed in Jarzemba and Manteufel (1996)
Fraction of year blanket saturated due to precipitation	—	—	—	constant	0.0054	Assumed in Jarzemba and Manteufel (1996)
Annual irrigation rate (m/yr)	—	—	—	constant	1.52	NRC (1995) based on current water-use points
Fraction of irrigation water lost to evapotranspiration	—	—	—	constant	0.5	Assumed in Jarzemba and Manteufel (1996)
Fraction of year blanket saturated due to irrigation	—	—	—	constant	0.2	Assumed in LaPlante et al. (1995) based on Chambers and May (1994)
Blanket depth (m)	—	—	—	constant	1	Assumed in Jarzemba and Manteufel (1996)
Soil bulk density (g/cm^3)	—	—	—	constant	2	Assumed in Jarzemba and Manteufel (1996)
Saturated soil volumetric water content	—	—	—	constant	0.4	Assumed in Jarzemba and Manteufel (1996)

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Table 4-16. Listing of the reference parameter values for the volcanic ash blanket removal module proposed to be used in IPA Phase 3 (cont'd)

ASHRMOVO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Source	Distribution	Value	Source
Nuclide-specific distribution coefficient in volcanic ash (K_d in ash, cm^3/g)	—	—	—	constants	U = 35.0 Cm = 4000.0 Pu = 550.0 Am = 1900.0 Th = 3200.0 Ra = 500.0 Pb = 270.0 Pa = 550.0 Ac = 450.0 Np = 5.0 Sm = 245.0 Cs = 280.0 I = 1.0 Sn = 130.0 Ag = 55.0 Pd = 55.0 Tc = 0.1 Mo = 10.0 Nb = 160.0 Zr = 600.0 Sr = 15.0 Se = 150.0 Ni = 400.0 Cl = 0.0 C = 5.0	Sheppard and Thibault (1990)

Table 4-16. Listing of the reference parameter values for the volcanic ash blanket removal module proposed to be used in IPA Phase 3 (cont'd)

ASHRMOVO Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Source	Distribution	Value	Source
Nuclide-specific solubility (mol/L)	—	—	—	constants	U = 4.5e−5 Cm = 1.0e−6 Pu = 5.0e−6 Am = 5.0e−6 Th = 3.2e−9 Ra = 1.0e−7 Pb = 3.2e−7 Pa = 3.2e−8 Ac = 5.0e−6 Np = 1.6e−4 Sm = 5.0e−6 Cs = 1.0 I = 1.0 Sn = 5.0e−8 Ag = 1.0 Pd = 9.5e−4 Tc = 1.0 Mo = 1.0 Nb = 1.0e−8 Zr = 3.2e−10 Sr = 1.3e−4 Se = 0.1 Ni = 2.0e−3 Cl = 1.0 C = 1.0	Wilson et al. (1993); Kerrisk (1985)

Table 4-16. Listing of the reference parameter values for the volcanic ash blanket removal module proposed to be used in IPA Phase 3 (cont'd)

ASHRMOVO Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Source	Distribution	Value	Source
Bulk removal rate from blanket (1/yr)	—	—	—	constant	0.001	Assumed in Jarzemba and Manteufel (1996)

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4.13 FAULTING EVENTS—FAULTO MODULE OF TPA VERSION 3.1

4.13.1 Description of the Proposed IPA Phase 3 Model

The faulting events (FAULTO) module (Ghosh et al., 1997) evaluates the potential for direct disruption of WPs due to fault displacement in the proposed repository block at YM. In this module, faulting is treated as an external event that occurs in a block containing the repository without regard for tectonic mechanisms responsible for driving the faulting process. FAULTO takes published field data to simulate timing and amount of both largest credible and cumulative displacements along existing faults and new faults within the proposed HLW at YM. For a fault displacement, the FAULTO module calculates the percentage of repository area, number of WPs disrupted, and timing of the disruption, if it occurs. FAULTO does not evaluate the indirect consequences of faulting, including the possible effects of seismic shaking and fault displacement on groundwater hydrology and flow pathways.

4.13.2 Description of the TSPA-95 Model

TSPA-95 cited the papers by Gauthier et al. (1995) and Wilson et al. (1994) and assumed that the effects of potential faulting activity on the repository were negligible so these effects were not considered further.

4.13.3 Comparison of the Faulting Events Input Parameter Values

Since TSPA-95 did not consider faulting effects, a comparison between the initial data sets is not possible. Values proposed for the IPA Phase 3 base case are listed in table 4-17.

4.14 GROUND SURFACE DOSE ASSESSMENT—DCAGS MODULE OF TPA VERSION 3.1

4.14.1 Description of the Proposed IPA Phase 3 Model

The ground surface dose assessment (DCAGS) module is used to calculates dose to individuals from radionuclides spread on the ground surface. The dose is calculated by multiplying the areal density of each radionuclide by a ground surface DCF calculated by averaging 125 runs of the GENII-S program (Leigh et al., 1993) as described in Jarzemba and LaPlante (1996). The total dose to a receptor for each time period is then the sum of the doses from each radionuclide. Separate DCFs are used for critical groups located closer or further than 20 km from the repository. The DCFs for a receptor located less than 20 km from the repository include contributions only from direct exposure and inhalation. The DCFs for a receptor located more than 20 km from the repository includes contributions from direct exposure, inhalation, and ingestion of crops and livestock.

4.14.2 Description of the TSPA-95 Model

The only scenario in which radionuclides are spread in this manner is in the case of an extrusive volcanic eruption. Since the volcanism scenario is not developed in TSPA-1995, ground surface DCFs are not included in the analysis.

Table 4-17. Listing of the reference parameter values for the faulting events module proposed to be used in IPA Phase 3

FAULTO Input Values						
Parameter	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
	Distribution	Value	Source	Distribution	value	Source
Threshold displacement for disruption (m)	—	—	—	discrete	0.1 0.2 0.3 0.4	Assumed based on Stirewalt et al. (1995, 1996)
Standoff distance (m)	—	—	—	constant	0	Assumed based on Ghosh et al. (1997)
X location of faulting event in region of interest (m)	—	—	—	uniform	Min = 522500.0 Max = 572500.0	Assumed based on Ghosh et al. (1997)
Y location of faulting event in region of interest (m)	—	—	—	uniform	Min = 4053000.0 Max = 4103000.0	Assumed based on Ghosh et al. (1997)
Center of fault — x (m)	—	—	—	uniform	Min = 1.455e5 Max = 1.955e5	Assumed based on Ghosh et al. (1997)
Center of fault — y (m)	—	—	—	uniform	Min = 2.08e5 Max = 2.58e5	Assumed based on Ghosh et al. (1997)
Fault orientation	—	—	—	uniform	NW strikes = 25% NE strikes = 75%	Assumed based on Ghosh et al. (1997); Scott and Bonk (1984)
Strike orientation (degrees)	—	—	—	normal	90 % probability NW strike = N25°W to N40°W NE strike = N5°W to N25°E	Assumed based on Ghosh et al. (1997); Scott and Bonk (1984); Stirewalt et al. (1995)

Table 4-17. Listing of the reference parameter values for the faulting events module proposed to be used in IPA Phase 3 (cont'd)

FAULTO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	**Distribution**	**Value**	**Source**	**Distribution**	**value**	**Source**
Trace length (m)	—	—	—	uniform	NW = 2000 to 10000 NE = 3000 to 12000	Assumed based on Ghosh et al. (1997); Scott and Bonk (1984); Stirewalt et al. (1995)
Dip angle (degrees)	—	—	—	constant	90°	Assumed based on Ghosh et al. (1997); Scott and Bonk (1984); Stirewalt et al. (1995)
Fault zone width (m)	—	—	—	beta	alpha = 1.5 beta = 3.0 NW = 0.5 to 275 NE = 0.5 to 365	Assumed based on Ghosh et al. (1997); Spengler et al. (1994); Stirewalt et al. (1995)
Number of slip surfaces	—	—	—	constant	1	Assumed based on Ghosh et al. (1997); Spengler et al. (1993); Stirewalt et al. (1995)
Recurrence interval (yr)	—	—	—	constant	6.0e4	Assumed based on Electric Power Research Institute (1993)
Time of first largest event (yr)	—	—	—	uniform	Min = 0 Max = 1.0e4	Assumed based on Stirewalt et al. (1995, 1996)
Largest credible displacement (m)	—	—	—	uniform	NW Min = 0.045 Max = 0.25 NE Min = 0.060 Max = 0.450	Assumed based on Electric Power Research Institute (1993)

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Table 4-17. Listing of the reference parameter values for the faulting events module proposed to be used in IPA Phase 3 (cont'd)

FAULTO Input Values						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Parameter	Distribution	Value	Source	Distribution	value	Source
Cumulative displacement rate (m/yr)	—	—	—	uniform	NW Min = 0.0 Max = 5.0e−5 NE Min = 0 Max = 5.0e−5	Assumed based on Electric Power Research Institute (1993) Stirewalt et al. (1995) U.S. Geological Survey (1996)

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4.14.3 Comparison of the Ground Surface Dose Assessment Input Parameters Values

Since TSPA-95 did not consider volcanic scenarios, a comparison between the input parameter values is not possible. Values proposed to be used in the IPA Phase 3 are listed in table 4-18 for a receptor located less than 20 km from the repository and table 4-19 for a receptor located more than 20 km from the repository.

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Table 4-18. Listing of the ground surface dose conversion factors at distances less than 20 km proposed to be used as the reference parameter values for IPA Phase 3

Dose Conversion Factors — Ground Surface Pathway at Distances Less Than 20 km						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (rem/yr)/(Ci/m^2)	Source	Distribution	Value (rem/yr)/(Ci/m^2)	Source
U-238	—	—	—	constant	2.40e2	Jarzemba and LaPlante (1996)
Cm-246	—	—	—	constant	7.90e2	Jarzemba and LaPlante (1996)
Pu-242	—	—	—	constant	8.30e3	Jarzemba and LaPlante (1996)
Am-242m	—	—	—	constant	9.30e2	Jarzemba and LaPlante (1996)
Pu-238	—	—	—	constant	4.80e2	Jarzemba and LaPlante (1996)
U-234	—	—	—	constant	2.80e2	Jarzemba and LaPlante (1996)
Th-230	—	—	—	constant	4.80e2	Jarzemba and LaPlante (1996)
Ra-226	—	—	—	constant	5.70e2	Jarzemba and LaPlante (1996)
Pb-210	—	—	—	constant	2.40e2	Jarzemba and LaPlante (1996)
Cm-243	—	—	—	constant	1.10e4	Jarzemba and LaPlante (1996)
Am-243	—	—	—	constant	5.30e3	Jarzemba and LaPlante (1996)
Pu-239	—	—	—	constant	5.10e2	Jarzemba and LaPlante (1996)
U-235	—	—	—	constant	1.30e4	Jarzemba and LaPlante (1996)
Pa-231	—	—	—	constant	4.90e3	Jarzemba and LaPlante (1996)
Ac-227	—	—	—	constant	2.10e3	Jarzemba and LaPlante (1996)
Cm-245	—	—	—	constant	8.30e3	Jarzemba and LaPlante (1996)
Pu-241	—	—	—	constant	8.00e0	Jarzemba and LaPlante (1996)
Am-241	—	—	—	constant	5.30e3	Jarzemba and LaPlante (1996)
Np-237	—	—	—	constant	3.60e3	Jarzemba and LaPlante (1996)
U-233	—	—	—	constant	2.70e2	Jarzemba and LaPlante (1996)
Th-229	—	—	—	constant	1.00e4	Jarzemba and LaPlante (1996)
Cm-244	—	—	—	constant	4.70e2	Jarzemba and LaPlante (1996)

Table 4-18. Listing of the ground surface dose conversion factors at distances less than 20 km proposed to be used as the reference parameter values for IPA Phase 3 (cont'd)

Dose Conversion Factors — Ground Surface Pathway at Distances Less Than 20 km						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (rem/yr)/(Ci/m^2)	Source	Distribution	Value (rem/yr)/(Ci/m^2)	Source
Pu-240	—	—	—	constant	5.50e2	Jarzemba and LaPlante (1996)
U-236	—	—	—	constant	2.60e2	Jarzemba and LaPlante (1996)
U-232	—	—	—	constant	1.10e3	Jarzemba and LaPlante (1996)
Sm-151	—	—	—	constant	4.90e−1	Jarzemba and LaPlante (1996)
Cs-137	—	—	—	constant	4.80e4	Jarzemba and LaPlante (1996)
Cs-135	—	—	—	constant	3.00e0	Jarzemba and LaPlante (1996)
I-129	—	—	—	constant	2.20e3	Jarzemba and LaPlante (1996)
Sn-126	—	—	—	constant	4.80e3	Jarzemba and LaPlante (1996)
Sn-121m	—	—	—	constant	4.30e2	Jarzemba and LaPlante (1996)
Ag-108m	—	—	—	constant	0.00e0	Jarzemba and LaPlante (1996)
Pd-107	—	—	—	constant	2.20e−2	Jarzemba and LaPlante (1996)
Tc-99	—	—	—	constant	6.90e0	Jarzemba and LaPlante (1996)
Mo-93	—	—	—	constant	4.60e2	Jarzemba and LaPlante (1996)
Nb-94	—	—	—	constant	1.30e5	Jarzemba and LaPlante (1996)
Zr-93	—	—	—	constant	1.30e−1	Jarzemba and LaPlante (1996)
Sr-90	—	—	—	constant	2.40e1	Jarzemba and LaPlante (1996)
Se-79	—	—	—	constant	1.80e0	Jarzemba and LaPlante (1996)
Ni-63	—	—	—	constant	3.50e−3	Jarzemba and LaPlante (1996)
Ni-59	—	—	—	constant	1.40e−3	Jarzemba and LaPlante (1996)
Cl-36	—	—	—	constant	5.90e1	Jarzemba and LaPlante (1996)
C-14	—	—	—	constant	1.40e0	Jarzemba and LaPlante (1996)

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Table 4-19. Listing of the ground surface dose conversion factors at distances greater than 20 km proposed to be used as the reference parameter values in IPA Phase 3

Dose Conversion Factors — Ground Surface Pathway at Distances Greater Than 20 km						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value $\frac{(rem/yr)}{(Ci/m^2)}$	Source	Distribution	Value $\frac{(rem/yr)}{(Ci/m^2)}$	Source
U-238	—	—	—	constant	6.60e3	Jarzemba and LaPlante (1996)
Cm-246	—	—	—	constant	7.20e5	Jarzemba and LaPlante (1996)
Pu-242	—	—	—	constant	9.50e3	Jarzemba and LaPlante (1996)
Am-242m	—	—	—	constant	6.70e5	Jarzemba and LaPlante (1996)
Pu-238	—	—	—	constant	0.00e0	Jarzemba and LaPlante (1996)
U-234	—	—	—	constant	5.70e3	Jarzemba and LaPlante (1996)
Th-230	—	—	—	constant	1.00e5	Jarzemba and LaPlante (1996)
Ra-226	—	—	—	constant	2.40e5	Jarzemba and LaPlante (1996)
Pb-210	—	—	—	constant	1.20e6	Jarzemba and LaPlante (1996)
Cm-243	—	—	—	constant	4.90e5	Jarzemba and LaPlante (1996)
Am-243	—	—	—	constant	7.00e5	Jarzemba and LaPlante (1996)
Pu-239	—	—	—	constant	1.00e4	Jarzemba and LaPlante (1996)
U-235	—	—	—	constant	1.90e4	Jarzemba and LaPlante (1996)
Pa-231	—	—	—	constant	2.10e6	Jarzemba and LaPlante (1996)
Ac-227	—	—	—	constant	2.70e6	Jarzemba and LaPlante (1996)
Cm-245	—	—	—	constant	7.20e5	Jarzemba and LaPlante (1996)
Pu-241	—	—	—	constant	2.40e2	Jarzemba and LaPlante (1996)
Am-241	—	—	—	constant	7.00e5	Jarzemba and LaPlante (1996)
Np-237	—	—	—	constant	1.10e6	Jarzemba and LaPlante (1996)
U-233	—	—	—	constant	5.80e3	Jarzemba and LaPlante (1996)
Th-229	—	—	—	constant	7.30e5	Jarzemba and LaPlante (1996)
Cm-244	—	—	—	constant	3.90e5	Jarzemba and LaPlante (1996)

Table 4-19. Listing of the ground surface dose conversion factors at distances greater than 20 km proposed to be used as the reference parameter values in IPA Phase 3 (cont'd)

Dose Conversion Factors — Ground Surface Pathway at Distances Greater Than 20 km						
	TSPA-95 Values			Proposed IPA Phase 3 Reference Values		
Element	Distribution	Value (rem/yr)/(Ci/m^2)	Source	Distribution	Value (rem/yr)/(Ci/m^2)	Source
Pu-240	—	—	—	constant	1.00e4	Jarzemba and LaPlante (1996)
U-236	—	—	—	constant	5.40e3	Jarzemba and LaPlante (1996)
U-232	—	—	—	constant	1.80e4	Jarzemba and LaPlante (1996)
Sm-151	—	—	—	constant	1.10e2	Jarzemba and LaPlante (1996)
Cs-137	—	—	—	constant	1.20e5	Jarzemba and LaPlante (1996)
Cs-135	—	—	—	constant	1.00e4	Jarzemba and LaPlante (1996)
I-129	—	—	—	constant	3.30e5	Jarzemba and LaPlante (1996)
Sn-126	—	—	—	constant	4.30e4	Jarzemba and LaPlante (1996)
Sn-121m	—	—	—	constant	4.60e3	Jarzemba and LaPlante (1996)
Ag-108m	—	—	—	constant	0.00e0	Jarzemba and LaPlante (1996)
Pd-107	—	—	—	constant	8.90e1	Jarzemba and LaPlante (1996)
Tc-99	—	—	—	constant	4.60e3	Jarzemba and LaPlante (1996)
Mo-93	—	—	—	constant	1.10e3	Jarzemba and LaPlante (1996)
Nb-94	—	—	—	constant	1.30e5	Jarzemba and LaPlante (1996)
Zr-93	—	—	—	constant	3.10e2	Jarzemba and LaPlante (1996)
Sr-90	—	—	—	constant	7.30e4	Jarzemba and LaPlante (1996)
Se-79	—	—	—	constant	5.20e3	Jarzemba and LaPlante (1996)
Ni-63	—	—	—	constant	4.20e2	Jarzemba and LaPlante (1996)
Ni-59	—	—	—	constant	1.50e2	Jarzemba and LaPlante (1996)
Cl-36	—	—	—	constant	6.90e4	Jarzemba and LaPlante (1996)
C-14	—	—	—	constant	1.40e0	Jarzemba and LaPlante (1996)

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5 DISCUSSION OF POTENTIALLY SIGNIFICANT DIFFERENCES

Determination of the parameters that significantly influence overall performance of the repository can only be done properly with a sensitivity study. Even without the benefit of sensitivity study results, however, some general inferences can be made about which data set differences, identified through a side-by-side listing, are likely to be most important. Obviously, model abstraction differences can have a large effect on the ultimate repository performance. Since the analysis of appropriate repository PA model abstractions is being conducted in numerous NRC/CNWRA KTIs and the identification of differences between the NRC and the DOE approaches has been discussed elsewhere (Baca and Brient, 1996), the effects of individual model abstraction differences will not be discussed here.

Differences in the infiltration rate of water into the repository can have a significant effect on the performance of the repository. The infiltration rate affects the time of failure of the WPs, the release rate of radionuclides from the WPs, and the travel time through the unsaturated zone. Therefore, the difference in input values for the infiltration rate between the two codes should significantly affect the calculated dose to the receptor. TSPA-95 examined two separate cases of infiltration rate. The low infiltration scenario used infiltration rates that range uniformly from 0.01 to 0.05 mm/yr. The high infiltration scenario used infiltration rates that range uniformly from 0.5 to 2.0 mm/yr. The proposed IPA Phase 3 reference value is a uniform range more conservative than either scenario in TSPA-95, with a minimum of 1 mm/yr and a maximum of 10 mm/yr, averaged over the entire repository area. The DOE has indicated they will use larger infiltration rates in the future, so the differences between the two codes are likely to be less significant.

The funnel factor also affects the amount of water coming into contact with the WP so it will also have a significant effect on repository performance. The funnel factor will affect time of failure of the WPs and release rate of radionuclides from the repository. TSPA-95 used a constant value of four for the catchment area equivalent to the funnel factor. The proposed IPA Phase 3 reference value is a constant value of only 0.9 for the funnel factor. This value was selected on the assumption that flow in the unsaturated zone above the repository is divergent, so the funnel factor must be less than one. The value of 0.9 was selected as a conservative estimate of a value for divergent flow and continues to be studied by CNWRA staff. This lower value means that less water will come into contact with the waste so this value is less conservative.

Other parameters that could significantly affect performance measure results include unsaturated zone contaminant transport parameters of key elements. Key elements include those that one or more of its isotopes are predicted by TSPA-95 or IPA Phase 2 (Nuclear Regulatory Commission, 1995) to deliver a significant dose to the critical group. The sorption coefficient for several key radionuclides ranges are dissimilar enough to potentially cause a significant difference in the predicted performance of the repository. Key elements where TSPA-95 used a significantly smaller, more conservative range of values for at least one hydrostratigraphic unit are americium, cesium, radium, and technetium. Key elements for which the proposed IPA Phase 3 reference values are more conservative include lead and niobium. Smaller values for the sorption coefficient are conservative because less of the radionuclide will be trapped by the rock and it will take less time to travel through the unsaturated zone.

The solubility of key elements is also an important parameter in determining repository performance. This parameter affects the radionuclide release rate after the WP failure. Several key elements including curium, cesium, selenium, and technetium have significantly larger proposed IPA Phase 3 reference

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values than TSPA-95 used. These larger values are more conservative as they will predict a greater amount of radioactivity escaping the WP and thus a larger dose to the critical group.

Differences in initial inventory noted in section 3 include two-fold or larger discrepancies in the inventory of ^{242m}Am, ^{244}Cm, ^{245}Cm, and ^{246}Cm. Results from TSPA-95 and IPA Phase 2 (Nuclear Regulatory Commission, 1995) both indicate these radionuclides are moderate in terms of their contribution to the repository performance measures. While not conclusive, this indicates that the two- and three-fold initial inventory differences are unlikely to have significant differences in overall estimated repository performance measure results.

Finally, situations where no data set comparison could be made may potentially result in significant differences in performance measure results. Examples of this include the different abstractions used in TSPA-95 and proposed to be used in IPA Phase 3 for the EBS failure and the proposed inclusion of disruptive scenarios in the IPA Phase 3 which were not included in TSPA-95. The differences between the two studies due to different models are being studied elsewhere, so no attempt made in this paper to determine these differences.

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