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Attachment A: TRANSPARENCY AND TRACEABILITY IN PERFORMANCE ASSESSMENT

CONCERN

While the overall clarity and readability of the *Viability Assessment of a Repository at Yucca Mountain Volume 3: Total System Performance Assessment* (U.S. Department of Energy, 1998), significantly improved compared to TSPA-1993 (Wilson et al., 1994) and TSPA-1995 (TRW Environmental Safety Systems, Inc., 1995), there are still areas where DOE has not maintained adequate transparency, traceability, and consistency in its calculations. The Nuclear Regulatory Commission (NRC) views transparency and traceability in performance assessment (PA) as highly significant to preparation and review of the license application (LA) and is concerned that inadequate transparency and traceability may undermine DOE efforts to make a successful safety case.

IMPORTANCE

The lack of transparency and traceability in PA will impede NRC's ability to conduct a thorough and expeditious review of the LA. The key attributes of the NRC review process will include (i) quantitative reproducibility of DOE results, (ii) investigation of the effects of key factors at intermediate points in the calculation (i.e., "pinch points") that drive overall performance, and (iii) assessment of the DOE bases for conceptual model and parameter choices. Transparency and traceability depend, in part, on (i) clear identification of information flow from one component (or model) to another in the description of the TSPA, (ii) demonstration of consistent treatment of uncertain parameters sampled at the system and component levels, and (iii) clear description of various components of the TSPA. Transfer of information from components to the system code or *vice versa* in many instances is neither transparent nor traceable in the TSPA-VA. Consequently, it is difficult to evaluate the consistency of DOE calculations across and within the components of the system code and appropriate treatment of sampled parameters.

STATUS OF RESOLUTION

DOE recognizes that traceability of data transfer among models is a very important aspect of information flow (U.S. Department of Energy, 1998). DOE indicates that the Technical Basis document (Civilian Radioactive Waste Management System Management and Operating Contractor, 1998) explicitly identifies computer input and output data files for traceability purposes. DOE is also using improved graphical presentation and documentation of various analyses and concurs with the NRC comment that the results should allow the importance of alternative models to be evaluated. However, there are still areas as identified in the basis where lack of transparency and traceability impedes the review process.

ADDITIONAL BACKGROUND

The transparency and traceability of analysis in PA have been partly addressed in a letter on July 6, 1998, from NRC to DOE. However, the comments only addressed documentation of PA results, requiring that the results be presented in a manner that would allow the contribution of each alternative conceptual model to be evaluated. The NRC and CNWRA are currently expanding the Issue Resolution Status Report (Nuclear

Regulatory Commission, 1998) and are in the process of developing acceptance criteria on transparency and traceability for the TSPA-LA. DOE expects to address this topic through an internal document review process at future technical exchanges with the NRC.

BASIS

While the Technical Basis document provides the details of abstractions and input and output parameters for each component of the TSPA, the transfer of data and treatment of uncertain parameters in the total-system is not transparent and traceable in the TSPA-VA (U.S. Department of Energy, 1998). In spite of the detailed descriptions in the Technical Basis document, there are still areas where clear description of components (or models) is lacking. Several examples provide a basis for this NRC concern.

Information Flow From Components (or Models) to the System Code

There is not adequate discussion tying key inputs and intermediate results together for the flow of water in the unsaturated zone (UZ). Although there is general discussion of the overall system components and inputs (U.S. Department of Energy, 1998, sections 2 and 3), the key component-to-component information flow (U.S. Department of Energy, 1998, figure 2-13) is difficult to trace. There are no intermediate results presented in these sections that show the connection among the components used in flow calculations. The reviewer must refer to numerous chapters in the Technical Basis document (Civilian Radioactive Waste Management System Management and Operating Contractor, 1998) to develop specific understanding of how much water is flowing through the mountain and the fraction of water entering the waste package (WP). Because each chapter discusses only the conceptual model, input data, and base case results specific to a TSPA model component, it is either difficult or impossible to trace values for the water flow from the ground surface to the water table at various scales (e.g., mountain scale, drift scale, and WP scale). A "sample calculation" demonstrating the integration of intermediate outputs and their interdependencies would make the presentation clearer and aid the reviewer in the process of checking and/or reproducing the results.

Demonstration of Consistent Treatment of Uncertain Parameters

In the DOE TSPA-VA, only 177 uncertain parameters have been sampled in the RIP code whereas many hundreds of parameters are sampled in the component models external to the RIP code. Two topics with regard to parameter sampling for probabilistic analyses raised by the staff manifest themselves as transparency and traceability concerns: (i) potentially inadequate emphasis on the correlation among parameters and (ii) the inadequate sampling of parameters that could be significant to performance.

For abstracted coupled process models, correlation among uncertain parameters is commonly used to simulate the effects of coupling. It is not clear if the systematic analyses were conducted to determine whether input data from component models supplied to the RIP code reflects or accounts for such correlations. For example, it is not clear how the temperature history used to evaluate near-field thermohydrology and the onset of localized corrosion in the inner barrier material is also used to determine the SF dissolution rate inside the WP.

Deterministic flow fields are computed outside of the RIP code. These flow fields are generated with the TOUGH2 computer code and used to calculate transport in the UZ above and below the repository. The approach employs a detailed three-dimensional model that allows simulation of processes such as lateral flow in perched water regions to a degree that is not possible in a more abstracted model. However, the long run times for this model do not allow key uncertain parameters (van Genuchten parameters, porosities, permeabilities, etc.) to be sampled during code execution. Thus, model execution is limited to a small number of deterministic runs which provide the unsaturated zone flow fields that are utilized in evaluating repository performance. A more defendable approach to address concern about inadequate sampling would be to conduct a large number of detailed simulations covering a broad range of uncertain parameters and then imitate the behavior of this model through a highly abstracted model. This abstracted model would be used for the Monte Carlo simulations and could utilize PDFs for all uncertain parameters associated with the model.

Clear Description of Various Components of the TSPA

Another example of lack of the transparency in the TSPA-VA is the use of a so-called dilution factor to account for the effects of vertical and horizontal transverse dispersion during saturated zone (SZ) transport of dissolved radionuclides.

In the TSPA-VA, radionuclide transport for the SZ is simulated using a bundle of six stream tubes along which the 1D advection-dispersion equation is solved. The effects of radionuclide sorption, radioactive decay, variations in the kinematic porosity, and longitudinal dispersion are accounted for in the 1D transport simulations. Steady-state flow in a stream tube is divergence free; thus, neither water nor dissolved radionuclides cross the stream tube boundaries, hence, transverse dispersion can be directly accounted for.

Because the method used to simulate transport is inconsistent with the assumption made in TSPA-VA that transverse dispersion will significantly reduce saturated zone concentrations, the effects of transverse dispersion are simulated by dividing the effluent concentrations from the stream tubes by the dilution factor. This dilution factor, which is assumed to be log-uniformly distributed between 1 and 100, was obtained by formal expert elicitation. It is difficult if not impossible for the reviewer to directly relate the dilution factor to horizontal and vertical transverse dispersivities or dispersion coefficients. The reviewer may attempt to infer the magnitudes of transverse dispersion implied by the dilution factor, but there is insufficient information in the TSPA-VA to do so. Whenever a lumped parameter is used to reflect a complex physical process, DOE should show the mathematical basis for the approximation.

REFERENCES

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Attachment B:
MAJOR CROSS-CUTTING ISSUES IN TSPA-VA

1. *The staff is concerned that the experiments or scientific development needed for the LA may not keep pace with the proposed deadline for conceptual model and code development.*

DOE has identified numerous areas where work would be completed and included in the LA. One significant concern is DOE's ongoing effort to explore design alternatives to make the safety case more robust. Late design changes may preclude gathering the data needed to support models used in PA at licensing. A significant number of design parameters have not been finalized. DOE has mentioned several times at Appendix 7 meetings that the TSPA code development for LA would be completed by August 1999. In light of this date, it is not clear how DOE will incorporate model-level changes to their TSPA for LA in the areas where further data collection and model development are necessary. For example, DOE WP and EBS design for VA will potentially change in the near future. These design changes may force substantial modifications in the TSPA approach to performing the repository near-field calculation. As an example, changes to the container materials and their placement as inner or outer barriers in the WP design may affect the quantity and the chemistry of dripping water contacting fuel cladding, leading to localized corrosion or stress corrosion of the cladding and accelerating the contact of water with SF. It is not clear if the design changes can be implemented in the DOE TSPA during the available time. Data may not be available to adequately support the safety case for any significant design changes.

2. *Large parameter ranges used in the calculation may not be technically defensible because of risk dilution.*

Large parameter ranges used in the TSPA may not be technically defensible if the underlying conceptual model is invalid for extreme values sampled from the distribution. This problem can be avoided by using alternative conceptual models representing phenomena at various ranges. For example, the effective porosity of tuff in the saturated zone ranges over four orders of magnitude and thus may reflect predominantly matrix or predominantly fracture flow at its extremes. However, the conceptual model currently used does not encompass the two flow regimes. An alternative approach would be to specify separate distributions for fracture porosity and matrix porosity and apply these values to flow in the fracture and matrix. Similar observations can be made for the corrosion rate parameter. Just as for the parameters with large ranges, it may be questionable whether the modeling abstraction is adequate in covering the whole range of the simulation period (10^4 to 10^6 yr). Conceptual models valid for the early simulation period (i.e., 10^4 yr) may not be valid for the late simulation period (10^6 yr). For example, the model representing seepage into the drift and the amount of water contacting SF can be drastically different subsequent to rockfalls over a long period. Sufficient justification should be provided to ensure that the abstracted model is applicable over the entire simulation.

3. *The staff is concerned that less emphasis is given to the time-frame of analysis of 10^4 yr compared to 10^5 yr or 10^6 yr.*

Throughout the TSPA-VA, DOE performs calculations of repository performance with simulation periods for 10^5 and 10^6 years (see Chapter 5 in Vol. 3). In the case of showing system sensitivity to alternate model assumptions, presenting such results can mask the importance of the process in question during the 10,000 yr compliance period. For example, in Figure 5-23 on page 5-21 of TSPA-VA (U.S. Department of Energy,

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1998), DOE examines the sensitivity of dose as a function of time to juvenile failure of waste packages. The dose as a function of time is presented out to 10^5 yr for three cases; (i) no juvenile failures, (ii) base case, and (iii) the 95th percentile of juvenile failures (i.e., 8 WP failures at 1,000 yr after repository closure). After 10^4 yr, the three curves are identical giving the impression that the number of juvenile failures is not important to performance. However, for the first 10^4 yr, the three curves vary by orders of magnitude and this parameter may be the most sensitive in the entire model for the first 10^4 yr. Although DOE notes the difference in the curves at early times, the presentation is such that it can be easily overlooked. DOE should stress in this case, and in others throughout the document, those results that significantly affect dose during the 10^4 compliance period. Other examples where system sensitivity for 10^4 yr are potentially overlooked are (i) concrete modified water (p. 5-13 of U.S. Department of Energy, 1998), (ii) microbially influenced corrosion (p. 5-20), and (iii) cladding credit (p. 5-25). These alternative conceptual models for repository performance produced estimated peak annual doses in 10^4 yr that were on the order of several to tens of millirem which is within about one order of magnitude of a potential standard.

4. It is not clear whether or how DOE plans to validate expert elicitation data through experiments.

A substantial volume of data used in the TSPA-VA is based on expert elicitation (EE). Although the EEs in most cases have bounded data with conservativeness, it is not clear if DOE has plans and has adequate time to confirm data from EE through laboratory or field work.

5. The lack of appropriate connection between saturated and unsaturated zones may result in an underestimation of dose.

The transfer of information between different modules of the code appears to contain implicit assumptions that may result in a reduction of the dose calculated by the RIP code. After the code determines the mass of radionuclides that is released from the Engineered Barrier System, it spreads the mass for a subarea over the entire volume of water traveling through the subarea. Similarly, the radionuclides that are released from the unsaturated zone are redistributed within the saturated zone subareas. Only a small number of packages are expected to fail over the 10,000 year compliance period for the repository. Spreading these relatively sparse releases over an entire subarea will result in a reduction in the concentration of the radionuclides and a corresponding reduction in dose at the critical group location.

Attachment C:
SENSITIVITY RANKING OF KESAS

This attachment presents table C-1 which describes (i) the relationship between DOE's Principal Factors for the Repository Safety Strategy (PFRSSs) and NRC Key Elements of Subsystem Abstraction (KESAs), and (ii) the significance of uncertainties of these factors/elements to their respective repository performance models. The relationships between the PFRSSs and the KESAs are not always obvious because the PFRSSs generally describe a single repository subprocess and the NRC KESAs tend to describe a group of subprocesses loosely grouped by subsystem. The significance of the uncertainties are as given in TSPA-VA for the PFRSSs and are based on sensitivity and uncertainty analyses for the NRC KESAs. In certain cases, TSPA-VA results are based more on assumptions used in the models than on a fundamental understanding of repository subsystem components (e.g., potential lifetimes of C-22 for long time periods when no data exist for corrosion of this material for such times, groundwater travel times from the repository to the receptor location on the order of several kyr, etc.), so the significances listed in table C-1 should be viewed cautiously.

Table C-1. A comparison between the Principal Factors for the Repository Safety Strategy (DOE) and the Key Elements of Subsystem Abstraction (NRC). Significance of uncertainties for different time periods included are based on TSPA-VA and NUREG-1668.

Principal Factor for the Repository Safety Strategy	Significance of Uncertainty in DOE TSPA-VA			Equivalent NRC Key Element(s) of Subsystem Abstraction	Significance of Uncertainty in NRC TSPA		Rationale for NRC ranking
	10 kyr	100 kyr	1 Myr		10 kyr	50 kyr	
Precipitation and infiltration into the mountain	L	M	L	- Spatial and temporal distribution of flow - Quantity and chemistry of water contacting WPs and waste forms	H H	H H	-Distribution and quantity of water flowing into drifts has been found to be important in sensitivity analyses primarily because of juvenile failures
Percolation to depth	L	L	L	- Spatial and temporal distribution of flow - Quantity and chemistry of water contacting WPs and waste forms	H H	H H	-See above

Table C-1. A comparison between the Principal Factors for the Repository Safety Strategy (DOE) and the Key Elements of Subsystem Abstraction (NRC). Significance of uncertainties for different time periods included are based on TSPA-VA and NUREG-1668 (cont'd).

Principal Factor for the Repository Safety Strategy	Significance of Uncertainty in DOE TSPA-VA			Equivalent NRC Key Element(s) of Subsystem Abstraction	Significance of Uncertainty in NRC TSPA		Rationale for NRC ranking
	10 kyr	100 kyr	1 Myr		10 kyr	50 kyr	
Seepage into drifts	H	H	H	- Spatial and temporal distribution of flow - Distribution of mass flux between matrix and fracture	H L	H L	-See above -Above a threshold all flux is in fractures
Effects of heat and excavation on flow (mountain-scale)	N/A	N/A	N/A	- WP corrosion (humidity , chemistry, and temperature) - Spatial and temporal distribution of flow	L	H	-In no case does the alloy C-22 WP fail from corrosion before 10 kyr
Effects of heat and excavation on flow (drift-scale)	L	M	L	- WP corrosion (humidity , chemistry, and temperature)	L	H	-See above
Dripping onto WP	L	L	L	- Spatial and temporal distribution of flow - Distribution of mass flux between matrix and fracture	H L	H L	-Distribution and quantity of water flowing into drifts has been found to be important in sensitivity analyses
Humidity and temperature at the WPs	L	L	L	- WP corrosion (humidity , chemistry, and temperature)	L	H	-See above
Chemistry of water on WP	H	L	L	- WP corrosion (humidity , chemistry, and temperature)	L	H	-See above

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Table C-1. A comparison between the Principal Factors for the Repository Safety Strategy (DOE) and the Key Elements of Subsystem Abstraction (NRC). Significance of uncertainties for different time periods included are based on TSPA-VA and NUREG-1668 (cont'd).

Principal Factor for the Repository Safety Strategy	Significance of Uncertainty in DOE TSPA-VA			Equivalent NRC Key Element(s) of Subsystem Abstraction	Significance of Uncertainty in NRC TSPA		Rationale for NRC ranking
	10 kyr	100 kyr	1 Myr		10 kyr	50 kyr	
Integrity of the outer carbon steel WP barrier	N/A	N/A	N/A	- WP corrosion (humidity , chemistry, and temperature) - Mechanical disruption of WPs (seismicity, faulting, rockfall, and dike intrusion)	L M	H L	-Scenario failures can contribute for the first 10 kyr, but thereafter, corrosion failures dominate.
Integrity of the inner corrosion-resistant WP barrier	H	H	M	- WP corrosion (humidity , chemistry, and temperature) - Mechanical disruption of WPs (seismicity, faulting, rockfall, and dike intrusion)	L M	H L	-See above
Seepage into WP	L	L	L	- Quantity and chemistry of water contacting WPs and waste forms - Radionuclide release rates and solubility limits	H M	H M	-Tc and I dose rates are roughly proportional to release rate.
Integrity of spent-nuclear fuel cladding	H	M	M	- WP corrosion (humidity , chemistry, and temperature) - Radionuclide release rates and solubility limits	L M	H M	-See above
Neptunium Solubility	L	M	L	- Radionuclide release rates and solubility limits	M	M	-See above

Table C-1. A comparison between the Principal Factors for the Repository Safety Strategy (DOE) and the Key Elements of Subsystem Abstraction (NRC). Significance of uncertainties for different time periods included are based on TSPA-VA and NUREG-1668 (cont'd).

Principal Factor for the Repository Safety Strategy	Significance of Uncertainty in DOE TSPA-VA			Equivalent NRC Key Element(s) of Subsystem Abstraction	Significance of Uncertainty in NRC TSPA		Rationale for NRC ranking
	10 kyr	100 kyr	1 Myr		10 kyr	50 kyr	
Dissolution of uranium oxide and glass waste forms	L	M	L	- Radionuclide release rates and solubility limits	M	M	-See above
Formation and transport of radionuclide-bearing colloids	L	M	L	- Radionuclide release rates and solubility limits	M	M	-See above
Transport through and out of the engineered barrier system (including WPs)	L	L	L	- Retardation in fractures in the unsaturated zone	L	L	-Current model assumes no retardation in fractures
Transport through the unsaturated zone	L	L	L	- Retardation in fractures in the unsaturated zone - Distribution of mass flux between fracture and matrix	L L	L L	-Flow is almost always in fractures in TPA 3.2
Flow and transport in the saturated zone	M	M	M	- Flow rate in water-production zones - Retardation in water-production zones and alluvium	L H	L H	- 3 to 7 kyr groundwater travel time in the SZ -Retardation in alluvium significantly increases actinide transport time

Table C-1. A comparison between the Principal Factors for the Repository Safety Strategy (DOE) and the Key Elements of Subsystem Abstraction (NRC). Significance of uncertainties for different time periods included are based on TSPA-VA and NUREG-1668 (cont'd).

Principal Factor for the Repository Safety Strategy	Significance of Uncertainty in DOE TSPA-VA			Equivalent NRC Key Element(s) of Subsystem Abstraction	Significance of Uncertainty in NRC TSPA		Rationale for NRC ranking
	10 kyr	100 kyr	1 Myr		10 kyr	50 kyr	
Dilution from pumping	H	H	H	- Dilution of radionuclides in groundwater (well pumping)	M	M	-Pumping provides a moderate amount of dilution
Biosphere transport and uptake	M	M	M	- Dilution of radionuclides in groundwater (well pumping)	H	H	-See above
				- Location and lifestyle of critical group	L	L	-In NRC PA, the location and lifestyle of the critical group are constant, hence their models have no variability

Attachment D:
IMPORTANCE RANKING OF KESAS

This attachment presents table D-1 which ranks the relative importance to NRC PA of the NRC Key Elements of Subsystem Abstraction (KESA) based on NUREG-1668 and staff expertise/experiences. The relative importances listed here differ from the significances of the uncertainties presented in attachment C because the relative importances to NRC PA also consider the sensitivities of performance to the KESA as well as the current uncertainty level, as dictated by the parameters in the model and performance of the subsystem(s) associated with that KESA.

Table D-1. A listing of the relative importance to NRC PA of the Key Elements of Subsystem Abstraction based on NUREG-1668 and staff expertise/experience.

NRC Key Element of Subsystem Abstraction	Relative Importance to NRC PA Model		Rationale
	10 kyr	50 kyr	
WP corrosion (humidity , chemistry, and temperature)	M	H	No corrosion failures occur before 10 kyr in TPA 3.2. At this time there is no reason to believe that this will change as models become updated, however, the 10 kyr performance would be sensitive to this KESA if lifetimes were dramatically shorter. Currently, most WP corrosion failures occur between 10 and 50 kyr. If the longevity of weldments for C-22 container is taken into account in WP corrosion failure criteria, the relative importance of the KESA during the first 10 kyr may be higher.
Mechanical disruption of WPs (seismicity, faulting, rockfall, and dike intrusion)	M	L	Seismic failures can moderately contribute to 10 kyr doses. By 50 kyr, most packages have failed due to corrosion, so effects of scenario failure are less for the longer time period.

Table D-1. A listing of the relative importance to NRC PA of the Key Elements of Subsystem Abstraction based on NUREG-1668 and staff expertise/experience (cont'd).

NRC Key Element of Subsystem Abstraction	Relative Importance to NRC PA Model		Rationale
	10 kyr	50 kyr	
Quantity and chemistry of water contacting WPs and waste forms	H	H	Parameters such as infiltration, F_{ow}, F_{mult}, and subarea wet fraction were found very important in sensitivity analyses for both time periods. These parameters deal primarily with the quantity of water contacting waste rather than its chemistry. Also, these parameters have ranges that are currently very weakly justified. Responsibility for some of these important parameters may be "shared" with "Spatial and temporal distribution of flow." For example, the quantity of water contacting waste depends not only on flow patterns in the mountain, but also on the history of climate evolution, which is estimated by the spatial and temporal distribution of flow KESA.
Radionuclide release rates and solubility limits	M	M	Release rates for technetium and iodine are roughly proportional to dose. Solubility limit for neptunium may also be important.
Spatial and temporal distribution of flow	H	H	Infiltration was found very important in sensitivity analyses for both time periods. Responsibility for infiltration may be shared with "Quantity and chemistry of water contacting WPs and waste forms" because infiltration depends on the flow patterns in the mountain as well as the dynamics of climate.
Distribution of mass flux between matrix and fracture	L	L	Current NRC TPA 3.2 model has most flow and transport in the UZ in fractures where no retardation takes place. If flow were confined to the matrix, then radionuclides may be highly retarded. Defending that flow or transport (e.g., matrix diffusion) takes place in the matrix in the UZ may be extremely difficult. Current model is considered conservative and doses are still low.
Retardation in fractures in the unsaturated zone	L	L	As with "Distribution of mass flux between matrix and fracture," justifying retardation in fractures may be very difficult due to such things as fracture coatings with calcite interfering with the ability of the rock to sorb radionuclides. Current TPA model assumes no fracture retardation.

Table D-1. A listing of the relative importance to NRC PA of the Key Elements of Subsystem Abstraction based on NUREG-1668 and staff expertise/experience (cont'd).

NRC Key Element of Subsystem Abstraction	Relative Importance to NRC PA Model		Rationale
	10 kyr	50 kyr	
Flow rate in water-production zones	H	M	Groundwater travel times in the saturated zone are about 3 to 7 kyr in the current NRC PA model. This travel time provides significant protection for 10 kyr, but less so for 50 kyr.
Retardation in water-production zones and alluvium	H	H	Retardation in alluvium is likely the reason that doses for 10 kyr result mostly from technetium and iodine. For longer time periods, retardation in alluvium still affords protection and technetium and iodine are still strong contributors to dose, however, longer lived but retarded radionuclides (e.g., neptunium) also contribute to dose.
Dilution of radionuclides in groundwater (well pumping)	M	M	Dilution from well pumping at the receptor group location can provide for a moderate amount of dilution from aquifer concentrations.
Location and lifestyle of critical group	H	M	20 km receptor group location aids in minimizing doses from nuclides retarded in alluvium. For longer time periods, some of these nuclides can reach the receptor group location in some realizations.
Volcanic Disruption of Waste Packages	H	L	Current TPA 3.2 model assumes all contents of conduit-intersected WPs are pulverized to 10 microns (plus/minus one order of magnitude), incorporated, and ejected in the event. Relaxation of this conservative assumption will decrease doses, but justification may be difficult. Since the peak of the average dose history curve (i.e., the performance measure) is likely captured in the first 10 kyr, all volcanism KESAs are relatively unimportant for longer time periods. Since volcanism provides most of the risk for 10 kyr, this KESA is ranked "H" for that time period.

Table D-1. A listing of the relative importance to NRC PA of the Key Elements of Subsystem Abstraction based on NUREG-1668 and staff expertise/experience (cont'd).

NRC Key Element of Subsystem Abstraction	Relative Importance to NRC PA Model		Rationale
	10 kyr	50 kyr	
Airborne Transport of Radionuclides	H	L	Doses from this scenario are highly sensitive to where (i.e., direction and distance) and how (i.e., particle sizes) radionuclides are transported. Since the peak of the average dose history curve (i.e., the performance measure) is likely captured in the first 10 kyr, all volcanism KESAs are relatively unimportant for longer time periods. Since volcanism provides most of the risk for 10 kyr, this KESA is ranked "H" for that time period.
Dilution of Radionuclides in Soil	H	L	This KESA determines doses after the volcanic event, which can have a moderate affect on the shape of the average dose history curve. Since the peak of the average dose history curve (i.e., the performance measure) is likely captured in the first 10 kyr, all volcanism KESAs are relatively unimportant for longer time periods. Since volcanism provides most of the risk for 10 kyr, this KESA is ranked "H" for that time period.

Attachment E:
MAJOR DIFFERENCE BETWEEN DOE AND NRC MODELING APPROACHES

Key Element of Subsystem Abstraction	Major Differences
WP Corrosion (temperature, humidity, and chemistry)	Significant differences exist between NRC and DOE conceptual models for corrosion. NRC models are based to a greater degree on fundamentals of electrochemical corrosion and experimental data. NRC models consider environmental factors to a greater degree such as oxygen partial pressure, temperature, pH and chloride ion concentration. DOE models include processes that are not included in NRC models such as dripping on WP, and modeling of pit and patch failure modes (NRC model has more simplistic failure modes). Parameter differences exist between NRC and DOE for those aspects of models that are similar. For example, corrosion rates for corrosion allowance material and corrosion resistant material are different than the NRC values and DOE ranges are sufficiently wide to include alternate conceptual models. DOE relies on expert elicitation based on sparse data for corrosion rates.
Mechanical Disruption of WPs (seismicity, faulting, rockfall, and dike intrusion)	Significant differences exist regarding the model for dike intrusion geometry leading to more failures per dike intrusion in NRC results when compared to DOE. Magma flow conditions are also modeled differently by NRC and DOE. NRC assumes repository breach leads to filling of drifts, whereas DOE allows for only partial filling of drifts. Many differences exist between DOE and NRC rock fall calculations. For example, the NRC model implicitly considers the effect of multiple rock blocks falling in unison such that the "effective size" of the fall increases whereas the DOE model considers only individual rock blocks. Also, the DOE model included assessing rock fall-induced WP damage initiation and through-going crack. The NRC model considers only through-going cracks. DOE WP damage criteria were developed from modeling results while NRC model uses a maximum allowable plastic criterion to assess integrity. DOE assumes seismically induced rock fall took place throughout the region. However, only 39 percent of rock falls will hit WPs due to the WP spacing. The NRC model relates fractional area of rock fall to ground motion. Differences in the direct fault disruption models have not been assessed at the time of this writing.
Quantity and Chemistry of Water Contacting WPs and Waste Forms	Differences exist in the conceptual models for quantity and chemistry of water contacting waste. DOE models consider temporal variation in chemistry more completely than NRC. The conceptual models for dripping are significantly different between NRC and DOE; however, both are based on speculative assumptions. The NRC model involves 2 parameters (F_{ow} and F_{mult}) that represent numerous processes while the DOE model includes a combination of more detailed modeling for mountain and drift scales using both deterministic and stochastic approaches. The DOE model provides more credit for the (water

removal/diversion) effects of capillary exclusion while the NRC model includes a fixed percentage of water entering the drift.

Radionuclide Release Rates and Solubility Limits	In general, the DOE source term model (base case) is different from the NRC source term (base case) model. DOE models consider colloids and can calculate to 10^6 years while NRC models do not. DOE also assumes very long time credit for cladding integrity while NRC assumes no cladding credit in its base case, which is conservative. DOE has revised their estimates of Np solubility by two orders of magnitude (smaller) while NRC is still using the previous DOE value. Both NRC and DOE models use excessively wide (yet conservative) parameter ranges that could encompass alternative conceptual models/processes.
Spatial and Temporal Distribution of Flow	DOE assumes a step change in climate from dry to long-term average between 0 to 10^4 years after emplacement, whereas NRC models a smooth approach to the glacial maximum, which is reached at 40,000 years. DOE models water table rise associated with climate change, putting a pulse of radionuclides into the saturated zone when the water table rises and a delay of radionuclides when the water table falls. NRC does not model water table rise. DOE utilizes a three-dimensional model of unsaturated zone flow, but does not sample unsaturated rock properties including permeability and porosity of matrix and fractures. NRC abstracts unsaturated zone flow modeling into a simplified one-dimensional model in which rock properties can be sampled. NRC sampling of rock properties yields a larger variation in flow times than DOE modeling. DOE conducts 3-D modeling of flow from ground surface to the repository horizon, whereas NRC assumes vertical flow. DOE modeling includes a perched water zone between the repository and water table whereas NRC modeling does not.
Distribution of Mass Flux Between Fracture and Matrix	NRC modeling assumes that all flow occurs in either the matrix or in fractures, while DOE allows a combination of matrix and fracture flow within a single hydrostratigraphic unit. DOE calculates matrix permeabilities during calibration of the model to measured data, which results in significantly higher matrix permeabilities than the laboratory data from which NRC derives their values. The effects of these differences is that the DOE takes more credit for flow in the matrix, which results in longer flow times in the unsaturated zone. DOE uses a smaller range of sorption coefficients in the matrix with a lower median value than NRC. This will cause shorter transport times on average for retarded radionuclides, although the extended range of NRC modeling will cause some realizations to have very short travel times in the unsaturated zone.
Retardation in Fractures in the Unsaturated Zone	Both the NRC and DOE assume that there is no retardation in fractures in the unsaturated zone. DOE takes credit for matrix diffusion, while NRC does not. The effect of this difference is that transport of radionuclides in the unsaturated zone will be slower in the DOE model, particularly for radionuclides that sorb to the matrix.

Retardation in Water Production Zones and Alluvium	DOE derives alluvium matrix sorption coefficients from laboratory data, which are more conservative than sorption coefficients derived from NRC modeling. DOE includes retardation of radionuclides in the tuff while NRC does not consider retardation in the tuff. NRC sampling of alluvium matrix sorption coefficients includes a correlation among the values for Am, Pu, U, Np, and Th, whereas the DOE does not include this correlation. Length of alluvium transport path in the DOE model is allowed to vary for each streamtube, whereas the length of the alluvium transport path in the NRC model is fixed for each streamtube. It appears that transport time in the saturated zone in the DOE model is shorter than in the NRC model.
Volcanic Disruption of Waste Package	DOE assumes that even if there is a volcanic event in the repository area, there are processes that may preclude a release of radionuclides (e.g., the waste package does not fail, the conduit does not strike the waste package, etc.). NRC modeling assumes that if a volcanic event occurs, waste is ejected and dispersed. DOE has a larger sampled range of the number of waste packages affected during a volcanic event. The NRC modeling is more conservative than the DOE modeling.
Airborne Transport of Radionuclides	The ash dispersion model following release due to an extrusive event is the same for both NRC and DOE. Parameters show some differences, for example, DOE models lower energy eruptions than NRC. There are sufficient similarities that NRC should be able to simulate DOE results if their parameters are used. DOE assumes a significantly larger value for the fuel particle size than NRC. DOE samples the direction wind is blowing at time of volcanic event from a wind rose diagram, whereas NRC assumes that the wind is blowing directly towards the critical group at time of eruption. The NRC modeling is more conservative than the DOE modeling.
Dilution of Radionuclides in Groundwater (well pumping)	Unlike the TPA Version 3.2 code, the TSPA-VA does not explicitly account for dilution of radionuclide concentrations due to well pumping. In the TSPA-VA, it is assumed that the radionuclide concentration in the water pumped from a well is equal to the maximum resident concentration in the aquifer (effectively assuming all well water is drawn from the center-line of the radionuclide plume). However, simply because the TSPA-VA does not account for borehole dilution, its estimates of well bore radionuclide concentrations are not necessarily much greater. In the TPA Version 3.2 code, the UZFT and SZFT modules simulate the transport of radionuclides and not the change in radionuclide concentrations as is done in TSPA-VA. Concentrations are computed in TPA Version 3.2 when the radionuclides are captured and pumped from the aquifer by dividing the mass (or activity) captured by the pumping well per unit time by the volumetric pumping rate (100 percent mass capture is assumed for the farming receptor group). Unlike the TSPA-VA, the TPA Version 3.2 code assumes there is no reduction in mass arrival rates due to vertical or horizontal transverse dispersion. In TPA Version 3.2, the well field providing water to the farming receptor group is assured to capture the entire breadth and depth of any plume of radionuclides emanating from the repository. DOE accounts for the effects of transverse dispersion by dividing the

concentrations at the downstream end of each tube by a so-called dilution factor that is log-uniformly distributed from 1 to 100. Everything else being equal, one would expect that the TSPA-VA approach used to account for dilution between the repository and the well head would lead to wellbore concentrations that are at most a factor of 40 greater than those computed using the approach of TPA Version 3.2.

Dilution of Radionuclides in Soil (surface processes)	NRC conceptual models include credit for the effects of ash blanket dilution (e.g., surface erosion, leaching, decay) over a much longer time frame than DOE. DOE models account for only leaching and decay for the year the dose is calculated but not beyond. Parameter differences cannot be determined because DOE has not provided in the VA or supporting documentation the parameters used for calculating the leaching factor. Both DOE and NRC models for soil dilution appear to be implemented deterministically.
Location and Lifestyle of Critical Group	NRC and DOE define a critical group with the same assumed lifestyle and location. The conceptual models (GENII-S) used by both NRC and DOE for calculating DCFs are identical. The parameter selections are generally consistent, with some differences in consumption rates and other demographic parameters that DOE has obtained from their local surveys. DOE uses a less conservative mass loading factor for inhalation than does NRC. Significant differences in the implementation of the dose modeling are apparent. DOE uses a stochastic approach involving GENII-S runs outside of the PA code to calculate all-pathway, radionuclide-specific DCF distributions. The DCF distributions for each radionuclide are then sampled for each realization of the DOE PA code. This sampling includes a correlation among radionuclides based on DCF magnitude that is not included in the NRC approach. NRC uses deterministic GENII-S runs outside the TPA code based on fixed central parameter values to generate lookup tables of DCFs for each exposure pathway and radionuclide. Because DOE DCFs aggregate all exposure pathways, they cannot be directly entered into the TPA 3.2 DCF lookup tables (which are pathway-specific). Despite the different approaches, the DOE mean DCFs are not very different from the fixed NRC values (approximately 30 percent difference).

Attachment F

MAJOR DIFFERENCES BETWEEN DOE AND NRC INPUT PARAMETERS

Attachment F
MAJOR DIFFERENCES BETWEEN DOE AND NRC INPUT PARAMETERS

Table 1. Unsaturated zone flow

Parameter/Assumption	DOE Value[1]	NRC Value[2]	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling[1]
Time period of climate change.	Range of 0 to 10,000 yr of present climate followed by 80,000 to 100,000 yr of long-term average climate (wetter and cooler). 100,000 year cycle. Step function transition between climates. [Table 2-7] [2-7] [2-16]. Superpluvial climate can occur after 80,000 yr.	10,000 yr of similar to present climate (or slightly hotter and drier) followed by wetter and cooler climate. 100,000 yr cycle, sinusoidal to glacial maximum.	Revise climato2.dat file to model a step increase to the long term average climate. Time of climate change cannot be sampled in TPA 3.2, but can be set to change at a mean value of 5000 yr from present.
Random perturbations in precipitation or infiltration to account for short-term variability in infiltration.	Not accounted for in VA, but sensitivity studies showed that impacts were very small [2-32].	Can be accounted for in TPA code, but in currently defined nominal case is not used.	None required.
Water table rise	80-120 m [2-7] 80 m for long-term average climate, 120 m for superpluvial climate [Table 2-7]	Not accounted for.	Decrease the thickness of the unsaturated zone below the repository by 80 m in each subarea.
Areal average mean infiltration at start	3.9-11 mm/yr varying by subarea, 7.65 mm/yr mean [Table 2-61]. (60% of realizations). I*3 in 10% of realizations. I/3 in 30% of realizations. [2-29]	1-10 mm/yr sampled uniformly for all subareas, 5.5 mm/yr mean.	Sample uniformly between 3.9 and 11 mm/yr. May have to do several runs of the code to account for I*3 and I/3 cases.

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Table 1. Unsaturated zone flow (cont'd)

Parameter/Assumption	DOE Value[1]	NRC Value[2]	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling[1]
Increase in precipitation at glacial maximum	Two times current precipitation during long-term average climate. [Table 2-5]. Three times current precipitation during superpluvial. [2-7].	Precipitation at glacial maximum is sampled uniformly between 1.5 and 2.5 times current precipitation.	Set precipitation multiplier to 2 because superpluvial climate cannot be reached in less than 80,000 yr.
Change in temperature at glacial maximum	Decrease of 10 °C [2-7].	Sampled uniformly between a decrease of 5 °C and a decrease of 10 °C.	Set change in temperature to a decrease of 10 °C.
Relationship between shallow infiltration and deep percolation	Calculated based on 3-D steady-state modeling using 15 deterministic simulations—no random sampling.	Assume no lateral diversion of flow and assume deep percolation equals average value of shallow infiltration for the subarea.	Appears to have little impact. Total percolation at the repository is calculated by the DOE to be nearly the same as infiltration at the surface. [2-108], [Figure 2-92].
Calculation of infiltration from precipitation	Includes all processes in the water balance equation, including runoff, transpiration by plants, and solar loading.	Does not include runoff, transpiration by plants, or solar loading.	According to TPA User's Guide p. 4-12, these neglected processes will be negligible under current conditions. TPA modeling may be conservative under future climates. Could be modeled by reducing the Mean Average Precipitation Multiplier slightly to account for the loss of precipitation from neglected processes.

[1]Table and page numbers in brackets in this column represent the location in the TSPA-VA Technical Basis Document (Department of Energy, 1998) at which this information is located.
[2]Table and page numbers in this column represent the location in the TPA 3.2 User's Guide (Center for Nuclear Waste Regulatory Analyses, 1998) at which this information is located.

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Table 2. Unsaturated zone flow and transport

Parameter/Assumption	DOE Value[1]	NRC Value[2]	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling[1]
Model of flow between repository and water table	3-D model developed at LBNL by Bodvarssen et al. (1997) [2-3].	1-D model, no lateral diversion [4-76].	DOE modeling shows significant non-vertical flow under repository [2-32]. This will result in longer flow paths for radionuclides, but may result in the bypassing strongly sorbing zeolitic zones [7-5].
Matrix diffusion	Modeled as a reduction in concentration of radionuclides within fractures. Diffusion rates used are listed on page 7-52.	Not modeled in UZFT [4-83].	Modify the Rd of radionuclides to match the slower movement of radionuclides due to matrix diffusion or utilize the matrix diffusion option in NEFTRAN. Effect appears to be about a factor of two on the peak mass flow rate for the 3-D model [Figures 7-27 and 7-28]. 2-D models show matrix diffusion plays only a minor role in reducing peak mass flow rate or time of peak mass flow rate [7-57]. The combined effects of matrix diffusion and matrix sorption is significant for release periods less than 5000 years [7-61, Figures 7-73 and 7-74].
Retardation within fractures	No sorption within fractures [7-4, 7-16].	Not modeled [4-82].	No changes needed.
Perched water between the repository and the water table	Modeled as a low permeability region [2-10] that diverts flow laterally along base of TSw unit [2-72]. May cause partial bypass of zeolitic unit.	Not modeled because 1-D model was used.	Total travel time of diverted water is not significantly altered due to the fast flow path through fractures [2-123]. Radionuclides may not contact highly sorbing CHn vitric and zeolitic units. Modeling in TPA 3.2 is difficult - may need to reduce the thickness

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Table 2. Unsaturated zone flow and transport (cont'd)

Parameter/Assumption	DOE Value[1]	NRC Value[2]	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling[1]
			of the CHn unit to attempt to model the water not coming into contact with this highly sorbing unit.
Model used to describe water flow through the unsaturated zone	Dual permeability model [2-10]. For base case, flow is assumed to be steady-state and all flow occurs in the fractures [2-92].	All flow is either in the matrix unless infiltration exceeds the saturated conductivity of the matrix in which case, all flow is in the fractures [4-77].	Effect not expected to be significant.
Faults in the unsaturated zone as a fast flow path	Modeled in 3-D model [2-10].	Not currently modeled.	Travel times calculated by TPA 3.2 in the UZ are generally very short so not modeling the fast flow paths should not have a significant effect on results.
Matrix permeability	Varies by hydrogeologic unit. See Table 2-19 to 2-23 of VA for base values.	Varies by hydrogeologic unit. See input file for values.	Map values in Tables 2-19 to 2-23 of the TSPA-VA Technical Basis Document (Department of Energy, 1998) to a distribution for the TPA input file.
Matrix porosity	Varies by hydrogeologic unit. See Table 2-19 to 2-23 of VA for base values.	Varies by hydrogeologic unit. See input file for values.	Map values in Tables 2-19 to 2-23 of the TSPA-VA Technical Basis Document (Department of Energy, 1998) to a distribution for the TPA input file.
Fracture permeability	Varies by hydrogeologic unit. See Table 2-19 to 2-23 of VA for base values.	Varies by hydrogeologic unit. See input file for values.	Map values in Tables 2-19 to 2-23 of the TSPA-VA Technical Basis Document (Department of Energy, 1998) to a distribution for the TPA input file.

Table 2. Unsaturated zone flow and transport (cont'd)

Parameter/Assumption	DOE Value[1]	NRC Value[2]	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling[1]
Fracture porosity	Varies by hydrogeologic unit. See Table 2-19 to 2-23 of VA for base values.	Loguniform distribution Min = 1e-3 Max = 1e-2	Map values in Tables 2-19 to 2-23 of the TSPA-VA Technical Basis Document (Department of Energy, 1998) to a distribution for the TPA input file.
Colloids	Modeled based with a 1-D dual porosity transport model with only fracture flow [7-41], extended to account for 3-D transport and advective flow between fractures and matrix. No matrix diffusion for colloids [7-18].	Not modeled.	Significantly decreases travel time for highly sorbed radionuclides (like Pu) [7-45]. Model irreversible colloids in TPA by reducing the fracture Rd for elements in colloids to a value less than 1. Model reversible colloids by reducing the Matrix Kd in all units by a factor of 1+Kc, the bulk colloid partition coefficient.
Dispersion of plume below repository	Modeled based on Fick's law [7-15]. Dispersion coefficient is normal with 1% quantile = 7.5	Longitudinal dispersion = 0.1 (fraction of layer).	Due to size of repository footprint compared to path length to the water table, dispersion is not expected to have a major impact on calculations [7-15]. Model in TPA by setting dispersion values to a normal distribution with min = 0.015 (fraction of layer) max = 0.118 (fraction of layer)
Sorption of radionuclides on rock matrix	Modeled using Kds [7-15]. Kd values from range of tufaceous aquifer and the deeper carbonate aquifer in Meijer, 1992.	Modeled using Kds.	Match Kd distributions in tpa.inp file to values in Table 7-3 of VA.

Table 2. Unsaturated zone flow and transport (cont'd)

Parameter/Assumption	DOE Value[1]	NRC Value[2]	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling[1]
Thermal impacts on radionuclide transport	Not modeled because impacts will be the most significant during the first 2,000–3000 yr—before significant quantities of radionuclides are released.	Not modeled.	No change necessary.
Bulk colloid partition coefficient (Kc)	loguniform min=1e-5 max=10 [7-54]	Not modeled.	Used to model colloidal transport.

[1]Table and page numbers in brackets in this column represent the location in the TSPA-VA Technical Basis Document (Department of Energy, 1998) at which this information is located.
[2]Table and page numbers in this column represent the location in the TPA 3.2 User's Guide (Center for Nuclear Waste Regulatory Analyses, 1998) at which this information is located.

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Table 3. Saturated zone flow and transport

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Dilution of radionuclides	SZ flux (146,300 m^3) and dilution factor (1-100) (6.2–18 M•m^3)	Well pumping.	The well pumping rate can be changed at receptor location to reflect the combination of DOE's SZ flux times the dilution factor. The revised well pumping rate will be 0.15 to 15 M•m^3. This change will cause some increase in the expected dose due to a lower bound that is more than ten times less dilution.
Presence of Alluvium	Alluvium length varies (0.0 to 6.0 km).	Varies with streamtube (8–12 km).	Variation of alluvium length is not possible as a sampled variable. A few simulations could be done based on DOE's expected value and the conservative value of 0. With alluvium not present the dose will be large due to the loss of the sorption properties.
Darcy Flux	2.3 m/yr (long-term average).	Varies with streamtube) (~0.3 m/yr).	Darcy flux can be changed to match the DOE value. This change will decrease the travel times which could result in the 10,000 yr dose being dominated by Np rather than I and Tc as is currently the case in TPA3.2.
Alluvium Porosity	Mean = 0.25; SD = 0.075	0.1–0.15.	Truncated normal uniform 3 standard deviations about the mean or 0.025–0.475 can be used. This range

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Table 3. Saturated zone flow and transport (cont'd)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
			will increase the variation in velocity resulting in a larger spread in arrival times.
Tuff porosity	1e-5, 0.02, 0.23 Logtriangular.	0.001–0.01 Loguniform.	DOE range for porosity can be used directly in TPA3.2. The much broader range will increase the range in transport times in the tuff. The high end of the range will make flow behave as a porous media rather than a fractured rock.
Alluvium Kd Np237	Kd = 5–15 mL/g Uniform.	Rf = 1–3,900 (Kd = 0 - 225 mL/g) Lognormal.	The TPA3.2 code uses retardation factors so the DOE Kd values will be transformed to Rfs (i.e., 87–260). This range is larger, however, the previous low value of 1 is replaced with an Rf of 87, which will eliminate early release of Np.
I129	Kd = 0.0.	Rf = 1–4 Loguniform.	Change retardation factor to 1.0 to reflect DOE value. Travel time will be reduced, which should affect 10,000 yr dose.

Table 3. Saturated zone flow and transport (cont'd)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Tc99	Kd = 0.0	Rf = 1–30 Loguniform	Change retardation factor to 1.0 to reflect DOE value. Travel time will be reduced, which should affect 10,000 yr dose.

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Table 4. Biosphere

Parameter/Assumption	DOE Value*	NRC Value	Comments and potential TPA 3.2 Revisions to Emulate DOE Modeling
Population Scale Factor	1.0	1.0	None required.
Soil/Plant Transfer Scale Factor	0.117—8.51	1.0	Effects are expected to minor.
Animal Uptake Scale Factor	0.117—8.51	1.0	None required.
Human Dose Factor Scale Factor	1.0	1.0	"
Surface Soil Plow Depth (cm)	15	15	"
Surface Areal Soil Density (kg/m^2)	225	225	"
Deep Areal Soil Density (kg/m^3)	1,500	1,500	"
Roots in Upper Soil (fraction)	1.0	1.0	"
Roots in Deep Soil (fraction)	0.0	0.0	"
External/Inhalation Exposure			
Chronic Plume Exposure (hr)	not provided	3,384 (farmer) 2,184 (resident)	Effects are expected to minor.
Inhalation Exposure (hr/yr)	3,869 (no resident)	4,200 (farmer) 2,184(resident)	"

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Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Mass Load (g/m^3)	1.93E-5 1.93E-5	Range:[1.0E-2, 1.0E-4]	Key parameter for volcano scenario with large uncertainty. TPA value is based on CNWRA/NRC consensus; DOE value is comparatively low but is within range of values reported for soil (no literature values for ash have been identified and therefore must be estimated).
Soil Exposure Duration (hr)	1,578 (no resident)	1,800 (farmer) 364 (resident)	Effects are expected to be minor.
Home Irrigation Rate (in./yr)	71 61—66	58 (current) 41 (pluvial)	Effects are expected to be minor.
Home Irrigation Duration (mo/yr)	12 12	9 (current) 12 (pluvial)	Effects are expected to be minor.
Ingestion Exposure			
Crop Resuspension Factor (m^{-1})	1.0E-5 1.0E-5	2.0E-7 (ash) 4.4E-10 (soil)	Effects are expected to be minor.
Crop Deposition Velocity (m/s)	0.001	0.001	None required.
Crop Interception (fraction)	0.40	0.40	None required.
Soil Ingestion Rate (mg/day)	410	50	Difference requires further investigation (do not know sensitivity).

Table 4. Biosphere (cont'd)

Parameter/Assumption	**DOE Value***	**NRC Value**	**Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling**
Drink Water Holdup Duration (days)	0	0	None required.
Drink Water Consumption (L/yr)	683.8	730	Effects are expected to be minor.
Terrestrial Food Ingestion			
Leafy Vegetables—Grow Duration (days)	67	80	Sensitivity analysis indicates difference is not important.
Other Vegetables—Grow Duration (days)	84	85	Difference is not important.
Fruit—Grow Duration (days)	119	80	Sensitivity analysis indicates difference is not important.
Grain—Grow Duration (days)	132.5	75	Sensitivity indicates difference is not important.
Leafy Vegetables—Irrigation Rate (in./yr)	36 35—36	60 (current) 43 (pluvial)	DOE estimate appears more realistic—TPA revision possible.
Other Vegetables-Irrigation Rate (in./yr)	41 39—40	60 (current) 43 (pluvial)	DOE estimate appears more realistic—TPA revision possible.
Fruit—Irrigation Rate (in./yr)	36 33—35	60 (current) 43 (pluvial)	DOE estimate appears more realistic—TPA revision possible.
Grain—Irrigation Rate (in./yr)	51 47.5—49	60 (current) 43 (pluvial)	Effects are expected to be minor.

Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Leafy Vegetables—Irrigation Duration (mo/yr)	3 3	3.0 (current) 6.0 (pluvial)	Effects are expected to be minor.
Other Vegetables—Irrigation Duration (mo/yr)	3.9 3.9	5.0 (current) 6.0 (pluvial)	"
Fruit—Irrigation Duration (mo/yr)	4.0 4.0	2.5 (current) 6.0 (pluvial)	"
Grain—Irrigation Duration (mo/yr)	5.55 5.55	5.0 (current) 5.0 (pluvial)	"
Leafy Vegetables—Yield (kg/m^2)	2.2	2	"
Other Vegetable—Yield (kg/m^2)	3.8	4	"
Fruit—Yield (kg/m^2)	1.9	3	"
Grain—Yield (kg/m^2)	0.62	0.54	"
Leafy Vegetables—Holdup (days)	1	1	None required.
Other Vegetables—Holdup (days)	14	14	"
Fruit—Holdup (days)	14	14	"
Grain—Holdup (days)	14	14	"

Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Leafy Vegetables—Consumption Rate (kg/yr)	8.01	6	Effects are expected to be minor.
Other Vegetables—Consumption Rate (kg/yr)	4.20	26	DOE value based on local survey data, TPA revision justifiable.
Fruit—Consumption Rate (kg/yr)	8.53	23	DOE value based on local survey data, TPA revision justifiable.
Grain—Consumption Rate (kg/yr)	0.17	34	DOE value based on local survey data, TPA revision justifiable.
Animal Product Consumption			Effects are expected to be minor.
Beef—Consumption Rate (kg/yr)	2.75	29.5	"
Poultry—Consumption Rate (kg/yr)	0.49	0	"
Milk—Consumption Rate (kg/yr)	4.42	100	DOE value based on local survey data, TPA revision justifiable.
Eggs—Consumption Rate (kg/yr)	4.03	3	Effects are expected to be minor.
Beef—Holdup (days)	20	20	None required.
Poultry—Holdup (days)	1	0	DOE includes poultry, TPA does not, TPA revision justifiable to include poultry based on survey data.
Milk—Holdup (days)	1	1	None required.

Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Eggs—Holdup (days)	1	1	None required.
Beef—Contaminated Water (fraction)	1	1	"
Poultry—Contaminated Water (fraction)	1	0	Effects are expected to be minor.
Milk—Contaminated Water (fraction)	1	1	None required.
Eggs—Contaminated Water (Fraction)	1	1	"
Fresh Forage Data			
Beef Forage—Dietary Fraction	1.0	0.56	DOE value is conservative, TPA value based on regional data, thus no revision required.
Milk Cow Forage—Dietary Fraction	1.0	0.56	DOE value is conservative, TPA value based on regional data, thus no revision required.
Beef Forage—Grow Duration (days)	57.5	46	Sensitivity analysis indicates parameter not important, no revision required.
Milk Forage—Grow Duration (days)	57.5	46	Sensitivity analysis indicates parameter not important, no revision required.

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Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Beef Forage—Irrigation Rate (in./yr)	73.5 66.5—69.5	60 (current) 43 (pluvial)	DOE estimate appears more realistic—TPA revision possible.
Milk Forage—Irrigation Rate (in./yr)	73.5 66.5—69.5	60 (current) 43 (pluvial)	DOE estimate appears more realistic—TPA revision possible.
Beef Forage—Irrigation Duration (mo/yr)	10.5 10.5	5.5 (current) 7 (pluvial)	Requires more information from DOE to determine basis for DOE value.
Milk Forage—Irrigation Duration (mo/yr)	10.5 10.5	5.5 (current) 7 (pluvial)	Requires more information from DOE to determine basis for DOE value.
Beef Forage—Yield (kg/m^3)	0.93	1.23	Effects are expected to be minor.
Milk Forage—Yield (kg/m^3)	0.93	1.23	"
Beef Forage—Storage Duration (days)	0	20	"
Milk Forage—Storage Duration (days)	0	1	"
Stored Feed			
Hen—Drinking Water Dietary Fraction	1	1	None required.

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Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Hen—Fraction of Contaminated Feed	1	1	None required.
Hen—Drinking Water Source	Contaminated Groundwater	Contaminated Groundwater	"
Hen Feed—Storage Duration (days)	14	14	"
Hen Feed—Grow Duration (days)	75	75	"
Hen Feed—Irrigation Rate (in./yr)	66 64—65	60 (current) 43 (pluvial)	Effects are expected to be minor.
Hen Feed—Irrigation Duration (mo/yr)	4.9	5	"
Hen Feed—Yield (kg/m^2)	0.62	0.54	"
Miscellaneous			
Absolute Humidity (kg/m^3)	not provided	0.008	Information from DOE on default parameters needed.
Leaf Surface Resuspension Factor (m^{-1})	not provided	1.0E-9	Information from DOE on default parameters needed.
Biomass (wet kg/m^2)			Information from DOE on default parameters needed.
Leafy Vegetables	not provided	2	

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Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Other Vegetables	”	2	
Fruit	”	3	
Grain	”	0.8	
Beef Feed—Stored	”	0.8	
Poultry Feed—Stored	”	0.8	
Milk Feed—Stored	”	1	
Laying Hen Feed—Stored	”	0.8	
Beef Forage—Fresh	”	1	
Milk Forage—Fresh	”	1.5	
Weathering Half Time (days)	not provided	14	Information from DOE on default parameters needed.
Translocation Fractions			Information from DOE on default parameters needed.
Leafy Vegetables	not provided	1.0	
Other Vegetables	”	0.1	
Fruit	”	0.1	
Grain	”	0.1	
Translocation—Animal			Information from DOE on default parameters needed.
Beef Feed—Stored	not provided	0.1	
Poultry Feed—Stored	”	0.1	
Milk Feed—Stored	”	0.1	
Laying Hen Feed—Stored	”	0.1	
Beef Forage—Fresh	”	1.0	
Milk Forage—Fresh	”	1.0	

Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Animal Water Consumption Rates (kg/day)			
Beef Cow	50	60	Additional DOE bases needed.
Poultry	0.3	0.3	
Milk Cow	60	100	Additional DOE bases needed.
Laying Hen (eggs)	0.3	0.3	
Animal Consumption Rates (wet weight — kg/day)			
Beef Feed—Stored	68.0	33	(DOE assumes 0% of stored feed so value =0).
Poultry Feed—Stored	0.12	0.08	
Milk Feed—Stored	55.0	73	(DOE assumes 0% of stored feed so value = 0).
Laying Hen Feed—Stored	0.12	0.11	
Beef Forage—Fresh	68.0	33	
Milk Forage—Fresh	55.0	73	Basis for DOE needed.
Chronic Breathing Rate (cm³/sec)	not provided	270	Information from DOE on default parameters needed.
Acute Breathing Rate (cm³/sec)	not provided	330	Information from DOE on default parameters needed.
Dry/Wet Ratio			Information from DOE on default parameters needed.
Leafy Vegetables	not provided	0.20	
Other Vegetables	"	0.25	
Fruit	"	0.18	
Grain	"	0.91	
Beef—Stored Feed	"	0.22	
Poultry—Stored Feed	"	0.22	
Milk Cow—Stored Feed	"	0.22	
	"	0.91	

Table 4. Biosphere (cont'd)

Parameter/Assumption	DOE Value*	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Hen (Eggs)—Stored Feed	"	0.22	
Beef Cattle—Fresh Forage	"	0.22	
Milk Cow—Fresh Forage			
Organ Weighting Factors	not provided	See 10 CFR 20.1003	Information from DOE on default parameters needed.
Leaching Factor			
Total Annual Precipitation (cm/yr)	not provided	15 (current) 37.5 (pluvial)	Information from DOE on leach model parameters needed.
Total Annual Irrigation Rate (cm/yr)	not provided	152 (current) 108 (pluvial)	Information from DOE on leach model parameters needed.
Total Annual Evapotranspiration (cm/yr)	not provided	80 (current) 48 (pluvial)	Information from DOE on leach model parameters needed.
Soil Volumetric Water Content (ml/cm^3)	not provided	0.35	Information from DOE on leach model parameters needed.
Soil Partition Coefficients (K_d) (L/kg)	not provided	Various	Information from DOE on leach model parameters needed.

*DOE uses parameter distributions for three types of receptors (subsistence farmer, resident farmer, Amargosa Valley population). For purposes of comparison, the value reported in the above table is the expected value/mean/mode for the Amargosa Valley population receptor. The rationale for this selection is that the Amargosa receptor habits are based on local survey data, which represents the best available information for defining receptor behavior pursuant to draft Part 63 requirements. The distribution range and type used by DOE may have considerable influence on the mean DCF calculated, however, such information is not provided in the above table.

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Table 5. Failure due to rockfall (SEISMO)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Damage Level	6 ranges, based on the size of rockfall. DL 4 may be roughly equivalent to rock category 3, DL 5 to category 4.	5 Rock categories, each covering a percentage of the repository block.	TPA 3.2 may result in a substantial number of waste package failures, when rockfall in rock category 4 takes place. This is similar to changes in DOE's Damage Level.
Rock Quality	4 categories (1 = strong)	5 categories (5 = strong)	There are similar numbers of rock categories. In TPA 3.2, rock fall in rock category 4 is the most significant precondition for large numbers of waste package failures. No change.
Peak Ground Velocity	135 cm/s required to cause maximum damage levels in good quality rock; peak ground velocity scaled from horizontal velocity times 2/3. Calculations do not appear to be consistent.	Seismic hazard curve is based on ground acceleration.	DOE's calculations appear inconsistent TSPA-VA Technical Basis Document (Department of Energy, 1998) and may be incorrect, leading to reduced levels of damage from rockfall. Although a direct comparison of seismic hazard curves has not been made, this should not represent a significant concern, since the TPA 3.2 seismic hazard curve is from DOE sources.

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Table 5. Failure due to rockfall (SEISMO) (cont'd)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
			DOE does not show any breached waste packages over 10,000 years. This is in contrast to peak ground velocities (PGVs) in DOE's seismic hazard curve that could result in significant or severe damage in medium quality rock and significant damage in strong rock, where rock sizes may be greater than 1000 kg. Use DOE's Seismic Hazard Curve to establish a range of waste package failures using NRC assumptions for other attributes.
Extent of Rockfall	Rockfall is throughout repository, up to rock quality.	Rockfall is throughout repository, subject to rock quality.	DOE's implementation of this assumption is not clear, but the concept is similar in both codes. No change.
Time Periods	Four time periods are used (0, 1ka), (0,10ka), (0,100ka), (0, 1M). Time of occurrence is selected randomly within the time period.	Four time periods are used. Seismic failures within each bin are assumed to occur at the beginning of the bin.	DOE does not show rock falls resulting in waste package failures during the first 10,000 years. There is no difference in the number of waste packages breached or the fraction of waste packages

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Table 5. Failure due to rockfall (SEISMO) (cont'd)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
			damaged in the shortest two DOE time periods. No change.
Event Sampling	(Median) PGVs are sampled and used to calculate rock damage.	Individual events and their acceleration are sampled.	Basing rock damage on median ground accelerations neglects the effects of larger events leading to significant rockfall and underestimates the impact from seismicity. Modify seismic hazard curves to represent median samples (assuming 500 + events). Modified seismic hazard curve could then be sampled to emulate DOE's. DOE's sampling of specific events results in large events having no significant impact because of limitations in DOE's sampling approach. See "peak ground velocity."
Fraction of Waste Packages Damaged	DOE shows no failures from rockfall, but an average 0.1% of the waste packages will experience accelerated corrosion of 6 or 24%.	Varies based on severity of seismic event. No corrosion failures in 10^4 yr.	DOE's accelerated corrosion could be mimicked by increasing the number of initial failures and turning off seismicity in the TPA 3.2 base case input file.

Table 6. Direct release from volcanic events (VOLCANO, ASHPLUME, ASHRMOVO)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Probability of igneous activity	1.0E-07 1/yr (p. 10-43) (probability of igneous activity in YM region).	1.0E-07 1/yr (cone formation in repository).	None.
Probability of waste extrusion given igneous activity in 1 Myr	0.05 (table 10-17).	1 (implicit).	Postprocessing adjustment to probability of volcanic impacts on the critical group.
Probability of waste extrusion given igneous activity in 10 kyr	0 (table 10-17).	1 (implicit).	No revision required because DOE modeling shows no impact from volcanism in 10,000 yr.
Number of package extruded given event extrudes waste	0.5 to 13 calculated from dimensions of cone and dike and fraction of waste that is entrained (table10–16h).	4 to 10 calculated from dimensions of cone and dike.	Volcanologists are modeling repository-conduit interactions.
Wind speed	Sampled using distribution in Jarzemba and LaPlante (1996) (table 10-3); Jarzemba (1997).	Exponential; average = 12.04 m/s.	None planned.
Wind direction	The direction wind is blowing is sampled from a wind rose diagram.	Wind is blowing directly towards the critical group in all realizations.	To emulate DOE, the probability of the wind blowing toward the receptor group would need to be included.

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Table 6. Direct release from volcanic events (VOLCANO, ASHPLUME, ASHRMOVO) (cont'd)

Parameter/Assumption	DOE Value	NRC Value	Comments and Potential TPA 3.2 Revisions to Emulate DOE Modeling
Spent fuel particulate size distribution	Values DOE uses from initial CNWRA investigations (Jarzemba and LaPlante, 1996). Logtriangular min = 0.01 cm peak = 0.1 cm max = 1.0 cm.	Logtriangular min = 0.0001 cm peak = 0.001 cm max = 0.01 cm [A-88].	Modify tpa.inp file to match DOE values.
Variation of dose with time after a volcanic event occurs	DOE only looked at peak dose for the realization in TSPA-VA: no equivalent model for predicting doses in times after the event.	Ash blanket radioactivity is reduced by erosion, leaching, and decay. Key removal parameter is erosion with $\lambda = 0.001$ per year.	None required, although peak doses could be averaged as a postprocessing step to match DOE modeling.

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