1. PURPOSE

Total System Performance Assessment Model/Analysis for the License Application describes the methodology, structure, validation, and application of the Total System Performance Assessment for the License Application (TSPA-LA) Model that has been developed to support the License Application (LA) to the U.S. Nuclear Regulatory Commission (NRC) for construction of a geologic repository for the safe disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) at Yucca Mountain, Nevada. The TSPA-LA is one of a series of iterative performance assessments (PAs) conducted over the life of the Yucca Mountain Project. The TSPA-LA Model evaluates the ability of the repository to adequately isolate nuclear waste following repository closure, as described in NRC Proposed Rule 10 CFR Part 63 ([DIRS 178394] and [DIRS 180319]).

1.1 INTRODUCTION

The TSPA-LA Model was developed to analyze the ability of the natural and engineered components of the Yucca Mountain Repository system to contain and isolate nuclear waste following repository closure. PAs and related supplemental analyses of the Yucca Mountain Repository have been conducted following the publication of the Nuclear Waste Policy Amendments Act of 1987, Public Law No. 100-203 [DIRS 100016]. Total System Performance Assessments (TSPAs) of the Yucca Mountain Repository have been iterative and periodically updated, each succeeding assessment building on and extending the scope and results of the previous TSPA. The iterative PAs incorporate both an improved understanding of the processes affecting repository performance and, through additional field observations and laboratory analyses, better identification and quantification of the values of the parameters used in the TSPAs. The most recent TSPA document applied the TSPA methodology to the Final Environmental Impact Statement for the Yucca Mountain Repository (Williams 2001 [DIRS 157307]).

The TSPA-LA Model was also used to perform analyses to address criteria contained in *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2) and in the Key Technical Issues related to a performance assessment (PA) identified in agreement with the NRC (Reamer 2001 [DIRS 158380], Attachment 1). The TSPA-LA Model evaluates the potential consequences of nuclear waste disposal at Yucca Mountain in terms of dose to potential receptors. The analyses presented in this document demonstrate the validity of the TSPA-LA Model in terms of its ability to represent the natural and engineered systems in and around the repository environment and the effects of possible disruptive events that could affect the performance of the Yucca Mountain Repository system.

1.1.1 Governing Regulations

Final rules from the U.S. Environmental Protection Agency (EPA) and NRC concerning the disposal of waste at Yucca Mountain have not yet been published. Until the final rules are published, the EPA and NRC rules are assumed, for the purposes of this document, to be unchanged from the proposed rules published in the Federal Register. Therefore, the analyses described in this report have been designed and executed consistent with the expectation that the final rules will be identical in all regards to the proposed rules. The discussion in this section is consistent with that expectation.

The NRC Proposed Rule 10 CFR 63, Parts E and L, consists of proposed changes to the existing rule, published as Implementation of a Dose Standard after 10,000 Years (70 FR 53313 [DIRS 178394], pp. 55313 to 55320), and the unrevised portions of the existing rule, published in the Federal Register as Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada (10 CFR Part 63 [DIRS 180319]). General references to the NRC Proposed Rule will cite both 70 FR 53313 [DIRS 178394] and 10 CFR Part 63 [DIRS 180319]. References to specific articles from either the proposed changes to the existing rule (e.g., 10 CFR 63.321 [DIRS 178394]) or to parts of the existing rule that have not changed (e.g., 10 CFR 63.322 [DIRS 180319]) will use, as shown here, only the DIRS reference number that applies. The same convention is followed when referring to the proposed and existing rules from the EPA. The EPA Proposed Rule 40 CFR Part 197, Subpart B, was published as Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV (70 FR 49014 [DIRS 177357], pp. 49014 to 49065). The existing rule, as published in the Federal Register, is 40 CFR Part 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV; Final Rule (66 FR 32074 [DIRS 155216], pp. 32074 to 32135).

The conceptual structure of the TSPA-LA Model and analysis of the Yucca Mountain Repository, as presented in this document, is based on regulatory requirements in NRC Proposed Rule 10 CFR Part 63 ([DIRS 178394] and [DIRS 180319]). The NRC Proposed Rule adopts the EPA Proposed Rule 40 CFR Part 197, Subpart B ([DIRS 177357] and [DIRS 155216]) regarding public health and safety standards for radioactive material for the Yucca Mountain Repository. The core requirement in the NRC Proposed Rule that ultimately gives rise to the conceptual structure of the TSPA-LA is the individual protection standard in 10 CFR 63.311 [DIRS 178394], specifying the dose standard for the reasonably maximally exposed individual (RMEI):

> “(a) DOE must demonstrate, using performance assessment, that there is a reasonable expectation that the reasonably maximally exposed individual receives no more than the following annual dose from releases from the undisturbed Yucca Mountain disposal system:
>
> > (1) 0.15 mSv (15 mrem) for 10,000 years following disposal; and
> >
> > (2) 3.5 mSv (350 mrem) after 10,000 years, but within the period of geologic stability.
>
> (b) DOE's performance assessment must include all potential environmental pathways of radionuclide transport and exposure.”

The NRC proposed rule requires that an application for a license to operate an HLW disposal facility at Yucca Mountain include a PA analysis, including the PA objectives for the geologic repository after permanent closure. Accordingly, 10 CFR 63.114(a) [DIRS 178394] states that any PA prepared in compliance with 10 CFR 63.113 [DIRS 180319] must:

> “(1) Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system used to define, for 10,000 years after disposal, parameters and conceptual models used in the assessment.
>
> (2) Account for uncertainties and variabilities in parameter values, for 10,000 years after disposal, and provide for the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment.
>
> (3) Consider alternative conceptual models of features and processes, for 10,000 years after disposal, that are consistent with available data and current scientific understanding and evaluate the effects that alternative conceptual models have on the performance of the geologic repository.
>
> (4) Consider only features, events, and processes consistent with the limits on performance assessment specified at § 63.342.
>
> (5) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes in the performance assessment. Specific features, events, and processes must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, for 10,000 years after disposal, would be significantly changed by their omission.
>
> (6) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, for 10,000 years after disposal, would be significantly changed by their omission.
>
> (7) Provide the technical basis for models used to represent the 10,000 years after disposal in the performance assessment, such as comparisons made with outputs of detailed process-level models and/or empirical observations (e.g., laboratory testing, field investigations, and natural analogs).
>
> (b) Any performance assessment used to demonstrate compliance with § 63.113 for the period of time after 10,000 years through the period of geologic stability must be based on the performance assessment specified in paragraph (a) of this section.”

Thus, the requirements state that any PA used to demonstrate compliance with the regulations should include a site description, considerations of uncertainty, alternative conceptual models (ACMs), and a features, events, and processes (FEPs) analysis as described in NRC Proposed Rule 10 CFR 63.114 [DIRS 178394]. Further, the FEPs identified as pertinent to the repository were screened for the postclosure 10,000-year compliance period as specified in NRC Proposed

Rule 10 CFR 63.342(a) [DIRS 178394], "DOE's performance assessments conducted to show compliance with §§ 63.111(a)(1), 63.321(b)(1), and 63.331 shall not include consideration of very unlikely features, events, or processes, *i.e.*, those that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal (less than one chance in 1,000,000 per year)." The NRC Proposed Rule 10 CFR 63.114(a)(2) [DIRS 178394] requires the PA to include concepts related to uncertainty in the estimates of the values of the parameters used in the TSPA-LA Model. The uncertainties used to provide the estimates of parameter values for the TSPA-LA Model address: (1) uncertainty in the epistemic or subjective sense related to knowledge about the appropriateness of assumptions used in an analysis, (2) spatial variability, and (3) uncertainty in the aleatory sense related to events that may or may not occur in the future. The regulation indicates that a PA analysis shall calculate outcome in terms of dose to the RMEI but include an uncertainty analysis that evaluates "how uncertainty in parameter values affects uncertainty in the estimate of dose" (66 FR 55732 [DIRS 156671], p. 55747, Supplementary Information III, Section 3.1).

The U.S. Department of Energy (DOE) must demonstrate, using a PA, that there is a reasonable expectation that, for 10,000 years following disposal, the RMEI receives no more than an annual dose of 15 mrem from releases from the undisturbed Yucca Mountain disposal system. DOE analysis must include all potential pathways of radionuclide transport and exposure. NRC Proposed Rule 10 CFR 63.303 [DIRS 178394] also adopts the EPA performance measures quoted from EPA Proposed Rule 40 CFR 197.13 [DIRS 177357] as follows:

> "(a) The NRC will determine compliance based upon the arithmetic mean of the projected doses from DOE's performance assessments for the period within 10,000 years after disposal."
>
> "(b) NRC will determine compliance based upon the median of the projected doses from DOE's performance assessments for the period after 10,000 years of disposal and through the period of geologic stability:"

The TSPA-LA Model calculates dose to the RMEI from the simulated release of radioactive materials from the Yucca Mountain Repository to the accessible environment, as specified in 40 CFR Part 197 ([DIRS 155216], p. 32133). The RMEI is located in the accessible environment where the groundwater path of the highest concentration of the contaminant plume would cross the southernmost boundary of the controlled area of the repository (at a latitude of 36° 40′ 13.6661″ North). This location is approximately 18 km from the repository footprint (66 FR 55732 [DIRS 156671], III Public Comments and Responses, 3.5, p. 55750).

The NRC Proposed Rule 10 CFR 63.305(b) [DIRS 180319] also describes specifications which indicate that: (1) the reference biosphere should incorporate FEPs consistent with present conditions in the Yucca Mountain region; (2) the PA should not project future demographic or biosphere conditions other than climate; (3) the PA should include reasonable assumptions about future geologic, hydrologic, and climatic conditions that could affect future conditions at the Yucca Mountain disposal site after repository closure; and (4) the PA should include biosphere pathways consistent with arid or semiarid conditions. Regarding climate, NRC Proposed Rule 10 CFR 63.342(c)(2) [DIRS 178394] states that,

> "DOE must assess the effects of climate change. The climate change analysis may be limited to the effects of increased water flow through the repository as a result of climate change, and the resulting transport and release of radionuclides to the accessible environment. The nature and degree of climate change may be represented by constant climate conditions. The analysis may commence at 10,000 years after disposal and shall extend to the period of geologic stability. The constant value to be used to represent climate change is to be based on a log-uniform probability distribution for deep percolation rates from 13 to 64 mm/year (0.5 to 2.5 inches/year)."

The NRC Proposed Rule 10 CFR 63.303(b) [DIRS 178394] states that, "Compliance is based upon the median of the projected doses from DOE's performance assessments for the period after 10,000 years of disposal and through the period of geologic stability for: . . ." The National Academy of Sciences considers the period of geologic stability at Yucca Mountain as approximately one million years (National Research Council 1995 [DIRS 100018], p. 72). To comply with this stipulation in the regulation, the TSPA-LA Model provides analyses that provide estimates of repository performance for one million years, where one million years is considered to be the period of geologic stability. According to NRC Proposed Rule 10 CFR 63.302 [DIRS 178394], "Period of geologic stability means the time during which the variability of geologic characteristics and their future behavior in and around the Yucca Mountain site can be bounded, that is, they can be projected within a reasonable range of possibilities. This period is defined to end at one million years after disposal." The one-million-year analyses are thus consistent with the NRC Proposed Rule 10 CFR 63.342 [DIRS 178394] and the EPA Proposed Rule at 40 CFR 197.25 [DIRS 177357]. The TSPA-LA Model developed for the FEPs screened for the 10,000 year time period was also applied to the one-million-year time period of geologic stability. The period of one million years after repository closure includes the peak dose from the Yucca Mountain Repository (Section 8).

The NRC proposed rule also requires DOE to assess a Human Intrusion Scenario and 10 CFR 63.321 [DIRS 178394] provides the individual protection standard for the Human Intrusion Scenario as follows:

> "(a) DOE must determine the earliest time after disposal that the waste package would degrade sufficiently that a human intrusion (see § 63.322 [DIRS 180319]) could occur without recognition by the drillers.
>
> (b) DOE must demonstrate that there is a reasonable expectation that the reasonably maximally exposed individual receives, as a result of human intrusion, no more than the following annual dose:
>
>> (1) 0.15 mSv (15 mrem) for 10,000 years following disposal; and
>>
>> (2) 3.5 mSv (350 mrem) after 10,000 years, but within the period of geologic stability.

> (c) DOE's analysis must include all potential environmental pathways of radionuclide transport and exposure, subject to the requirements at § 63.322 [DIRS 180319]."

1.1.2 Total System Performance Assessment Methodology

The TSPA process is represented on Figure 1-1 as a series of pyramid levels. Figure 1-2 separates the levels of the TSPA pyramid showing the information flow, the reports, and the feedback loops involved in the development of the TSPA-LA Model. The foundation of the TSPA pyramid consists of a repository-system characterization involving the assimilation of the information collected by scientists and engineers involved in site characterization and engineering design. The repository system and regional characterization entails data collection regarding waste properties and design of the repository facilities, as well as the regional geology, regional hydrology, and environmental characteristics of the Yucca Mountain site. The broad foundation of the pyramid represents the more than 20-year body of knowledge collected in the field and in the laboratory regarding the repository system. This accumulated body of knowledge was used to identify the set of possible FEPs that may affect the repository system after repository closure and also provide the basis for the second stage of the TSPA pyramid. The TSPA-LA Model is built on the family of analyses of the identified FEPs, including analyses related to the exclusion of FEPs that are either very unlikely, are not required for regulatory reasons, or that have a low impact on performance (Section 1.1.1).

The second stage of the TSPA pyramid consists of the development and testing of detailed models used to conceptually describe retained and probable FEPs and their outcomes regarding repository performance. The detailed conceptual models consist of sets of hypotheses, assumptions, simplifications, and idealizations that, together, describe the essential aspects of a system or subsystem of the repository relative to its performance. Model conceptualization identifies and selects FEPs that collectively comprise the scenarios considered in the conceptual models. An example of such a model or set of interconnected models is the description of the movement of water molecules and dissolved radionuclides by diffusive flow in rock pores or by advective flow in fracture openings in the unsaturated bedrock surrounding and below the repository and through the saturated zone (SZ) below the repository. Furthermore, because the TSPA process deals with future outcomes and includes uncertainty in both process descriptions and parameter values, there may be more than one ACM that provides a reasonable description of a particular system or subsystem. Therefore, the development and documentation of the supporting analyses are essential elements of the TSPA process. The supporting analyses capture uncertainty in probabilistic analyses that represent likely outcomes, based on the best available parameter values and the processes involved. This information serves as the foundation and source of input for the TSPA-LA Model. The documentation of the processes involved in the incorporation of uncertainty, the evaluation of ACMs, the treatment of conservatism, and the evaluation of FEPs in the supporting analyses provides input to the TSPA-LA Model.

The third stage of the TSPA pyramid involves the development of mathematical representations or abstractions of the conceptual models of the FEPs or scenarios, or both, that contribute to overall repository performance. The mathematical models consist of quantitative expressions of the process models developed in such a way that they can be used together to simulate repository performance. The mathematical models might include algebraic expressions, ordinary differential, partial differential, or integral equations characterizing accepted conservation laws, such as the conservation of mass, energy, or momentum, as well as appropriate constitutive equations that describe material behavior in the domain of the conceptual model. An example of one of the process models abstracted in mathematical and numerical form is a model describing the flow of water infiltrating into the bedrock and then percolating through the unsaturated zone (UZ) above the water table. Such a model would incorporate equations describing fluid flow and probable fluid interactions between the rock matrix and fractures in the rock, as well as descriptions of any other hydrologic, physical, and chemical processes needed to describe how water flows throughout the rock mass of the UZ.

The TSPA-LA Model includes a numerical representation of water flow through Yucca Mountain as an abstraction consisting of a series of statistical or mathematical expressions, including look-up tables, equations representing response surfaces, probability distributions, linear transfer functions, or reductions of model dimensionality. These inputs developed by the abstraction process were either implemented directly into the TSPA-LA Model or through a series of simplifying steps, depending upon the relative complexity or importance, or both, of the FEPs being abstracted. This abstraction, or progressive simplification of the conceptual models to more compact and usable numerical models, is the essence of this level of the TSPA pyramid. The models eventually used to analyze the projected evolution through time of the various components of the repository system are abstracted models that capture the salient features of the process models, along with their associated uncertainties.

The top level of the TSPA pyramid consists of the integrated total system model. The total system model is a numerical model used to simulate the behavior of the Yucca Mountain Repository system. The TSPA-LA Model incorporates the abstracted process models and/or the analyses that describe the model components and their submodels from their development to their implementation. Together these form the basis for the TSPA-LA Model.

The TSPA-LA Model integrates conceptual, mathematical, and computational models of the relevant FEPs that may affect repository performance as informed by site-specific information, relevant laboratory data, and natural analogues that assist in building the confidence in the long-term processes evaluated in TSPA-LA Model analyses. The TSPA-LA approach to the analysis of the repository system appropriately incorporates parameter distributions used to quantify uncertainty. Incorporating this uncertainty in multiple stochastic realizations of the TSPA-LA Model produces a long-term projection of repository performance. The simulations of repository performance thus provide a means for the defensible analysis of system behavior, incorporating process models and parameters based on scientific observations. The TSPA-LA Model then uses the parameter values and process models to assess the capability of the Yucca Mountain Repository System to comply with applicable radiation-protection standards contained in the governing regulations.

The use of the TSPA-LA Model to simulate Yucca Mountain Repository behavior and project future outcomes is aided by the development of scenario classes to assist in repository performance analyses. A scenario class is a set of related scenarios, incorporating groups of possible FEPs, that describe possible future repository conditions and share sufficient similarities that can be aggregated for performance analysis. The TSPA-LA scenario classes represent a wide range of future outcomes, including the Nominal, Early Failure, Igneous, and Seismic Scenario Classes, as well as a Human Intrusion Scenario.

The TSPA-LA Model builds on the family of analyses related to FEPs. The resulting TSPA-LA Model includes the results of analyses of the FEPs that were screened and included in the TSPA-LA Model development process. In addition, the TSPA-LA Model development was affected by the exclusion of FEPs that are either very unlikely, are not required for regulatory reasons, or that have a low impact on performance.

Probabilistic simulations provide a useful tool for the LA process and address issues raised by previous TSPAs conducted for the Yucca Mountain Repository. The TSPA-LA Model also provides results useful in addressing questions raised by internal and external reviews, such as those conducted by the U.S. Nuclear Waste Technical Review Board and the Performance Assessment International Review Team (OECD and IAEA 2002 [DIRS 158098]).

1.1.3 Treatment of Uncertainty

The TSPA-LA Model incorporates uncertainty in parameter values and event occurrence. Uncertainty in the TSPA-LA Model is characterized as either epistemic or aleatory uncertainty according to the following definitions (Hoffman and Hammonds 1994 [DIRS 107502]):

- **Epistemic Uncertainty**—Epistemic uncertainty pertains to the state of uncertainty in the state of knowledge concerning parameter values because there are limited data or there are alternative interpretations of the available data. The state of knowledge about the exact value of the parameter can increase through testing and data collection. Therefore, epistemic uncertainty can also be referred to as 'reducible uncertainty.'

- **Aleatory Uncertainty**—Aleatory uncertainty concerns whether or not there is a chance of occurrence of a feature, event, or process. For example, there can be uncertainty about whether or not a volcanic disruption can occur or not occur. Aleatory uncertainty may also be referred to as 'irreducible uncertainty' because no amount of knowledge will determine whether or not a chance event will or will not occur.

Maintaining a separation between aleatory and epistemic uncertainty strongly affects the design of the PA analyses conducted with the TSPA-LA Model. It may also strongly affect the design of individual TSPA-LA submodels. However, some parameters may have elements of both types of uncertainty. For example, UZ flow is modeled as occurring as an epistemically uncertain constant rate during each climate period, although percolation is dependent on the aleatory uncertainty in rainfall. The aleatory uncertainty in rainfall is accounted for in the calculation of the distribution of UZ flow rates. The manner in which the two forms of parameter uncertainty are handled in the TSPA-LA Model will ensure that the distributions of parameter values accurately reflect their development in the supporting process models and submodels.

1.2 TSPA-LA MODEL DEVELOPMENT PROCESS

The TSPA-LA Model analyses were conducted in a probabilistic framework. The TSPA-LA Model was used to calculate estimates of repository performance, including expected annual dose to receptors, groundwater concentrations at selected distances from the repository, and effects of disruptive events. The calculated results are consistent with the abstraction model inputs provided by analyses of the processes governing flow and transport of radionuclides expected to be released from the repository upon failure of the waste packages (WPs) containing SNF and HLW. The TSPA-LA Model uses Monte Carlo simulation techniques to address the uncertainty and/or variability in the values of the input parameters of the model. The TSPA-LA Model provides multiple realizations of the model's output by sampling input parameter values from assigned probability distributions spanning their defined ranges. To assist in TSPA-LA Model validation, several hundred to more than 1,000 realizations were simulated to ensure stochastic convergence and stability of the results. The simulations of each realization provided time histories of the annual dose or other performance measures. These results were analyzed for uncertainty and sensitivity with respect to the values of the input parameters at both total system and subsystem levels.

1.2.1 Features, Events, and Processes Analysis

The development of the TSPA-LA Model includes the identification and screening of FEPs that could affect the repository for up to one-million years after repository closure, although most FEPs are screened considering the first 10,000 years postclosure. Appendix I provides a mapping between the FEPs documentation and the TSPA-LA Model. The FEPs that were screened in were used to develop scenario classes for the TSPA-LA Model analyses. Figure 1-3 is a schematic representation of the development of the TSPA-LA Model and describes, for analysis purposes, the repository system divided into individual model components. Each individual model component represents a major process or set of processes of the total repository system. Figure 1-3 shows the model component areas as well as the scenario classes that were used to analyze repository performance under all expected conditions identified in the FEPs analysis, including a possible human intrusion into the repository.

1.2.2 Development of the Scenario Classes

The processes included in the principal model components in the TSPA-LA Model shown on Figure 1-3 were combined to evaluate the repository system performance for four scenario classes, seven modeling cases, and a stylized analysis of possible human intrusion into the repository. The underlying TSPA-LA Model incorporates all FEPs describing the fundamental processes governing repository performance and additional FEPs that describe disruptive events, as well as possible changes to those fundamental processes. The Nominal Scenario Class encompasses all processes affecting the integrity of the WPs containing SNF and HLW in the absence of disruptive events. These processes include WP degradation because of corrosion mechanisms, including general corrosion, stress corrosion cracking (SCC), localized corrosion, and microbially influenced corrosion (MIC). The Early Failure Scenario Class addresses FEPs that describe the potential for drip shield (DS) and WP early failure in the absence of disruptive events. The early failure scenarios include DSs and WPs that fail prematurely due to material defects or improper manufacturing conditions or pre-emplacement operations and practices, such as improper heat treatment or welding flaws. Early DS and WP failures are analyzed using the Drip Shield Early Failure (EF) Modeling Case and the Waste Package Early Failure (EF) Modeling Case.

The TSPA-LA Model includes two scenario classes that address the possibility that disruptive events may occur at or near the repository and that these events may affect repository performance. The Igneous Scenario Class comprises two modeling cases that address FEPs that describe igneous activity that could affect the repository. The Igneous Intrusion Modeling Case includes FEPs that account for the possibility that a dike containing magma could intrude into the repository and disrupt repository performance. The Igneous Intrusion Modeling Case includes all nominal flow-and-transport processes involving radionuclides after their release from WPs affected by an igneous intrusion. The Igneous Scenario Class also includes the Volcanic Eruption Modeling Case that addresses FEPs that describe a volcanic conduit(s) that invades the repository, destroys WPs, and erupts at land surface. The volcanic eruption disperses volcanic tephra and entrained waste into the atmosphere and deposits the contaminated tephra on land surfaces where the contaminated tephra becomes subject to redistribution by near-surface hydrogeologic processes.

The TSPA-LA Model also includes a Seismic Scenario Class, which is used to analyze possible seismic disruption of the repository and the disruption's effect on repository performance. The Seismic Scenario Class considers two modeling cases: (1) the Seismic Ground Motion (GM) Modeling Case addresses FEPs concerning damage to WPs, DSs, and commercial spent nuclear fuel (CSNF) due to vibratory ground motion; and (2) the Seismic Fault Displacement (FD) Modeling Case addresses the effects of fault displacement on WPs and DSs. The modeling cases simulate the degraded performance of damaged DSs and the release of radionuclides from WPs that are damaged due to seismic events. The transport of released radionuclides will be simulated using all the nominal processes that apply.

The NRC Proposed Rule 10 CFR 63.322 [DIRS 180319] requires DOE to assess a Human Intrusion Scenario, and 10 CFR 63.321 [DIRS 178394] provides the performance standard for the Human Intrusion Scenario. The TSPA-LA Model considered the Human Intrusion Scenario in a calculation that simulates a future drilling operation. The Human Intrusion Scenario considers an intruder drilling a land-surface borehole using a drilling apparatus operating under the common techniques and practices currently employed in exploratory drilling for groundwater in the region around Yucca Mountain. While drilling a borehole, the drilling apparatus directly intersects a degraded WP and continues subsequently into the SZ underlying Yucca Mountain. The human intrusion causes the subsequent compromise and release of waste in the penetrated WP. The TSPA-LA Model simulated the Human Intrusion Scenario occurring approximately 200,000 years after repository closure.

1.2.3 Incorporation of Uncertainty

The TSPA-LA contains over 300 parameters with uncertain parameter values that are described by probability distributions. In some cases, if there is significant uncertainty in parameter values, the TSPA-LA Model uses conservative estimates of the parameter values so as not to bias the results toward potentially optimistic projections of total system performance. To the extent practical, the TSPA-LA Model uses probability distributions to quantify uncertainty in parameter values.

A multi-disciplinary team of scientists and engineers was formed to conduct parameter uncertainty/variability reviews. The team identified parameter-value distributions using the most recent and relevant data and information about the repository system that was available from all sources. The information was used to quantify uncertainties in parameter values; provide insights for updating conceptual and numerical models, submodels, and abstractions; and provide additional lines of evidence about the possible future behavior of the repository. To the extent possible, the data and information regarding the parameter-value distributions have been incorporated into the TSPA-LA Model database.

The process used to evaluate unquantified uncertainties in parameter values contained in the parameter-valued distributions involved: (1) identifying the unquantified uncertainties to be evaluated; (2) developing more representative, quantified descriptions of those uncertainties; and (3) evaluating the implications of those newly quantified uncertainties with respect to repository performance. The impacts of these representations of parameter values to previously unquantified uncertainties were then evaluated using revised process models and supplemental TSPA-LA Model analyses using the revised uncertainty treatments. The results were documented accordingly in the TSPA-LA Model database. A Performance Assessment Systems Integration Team evaluated the review team's findings and recommended appropriate implementation using a risk-informed perspective.

The TSPA-LA Model analyses are probabilistic in order to capture the full range of possible future outcomes and the uncertainty and variability in the expected behavior of the repository system. The TSPA-LA Model calculates multiple realizations using distributions of values for uncertain parameters, and the model realizations are performed many times using many combinations of the distributed parameter values. Each combination of parameter values represents a subset of the full range of future outcomes.

1.2.4 Alternative Conceptual Models

ACMs are a means to specifically acknowledge model form uncertainty. An ACM is a set of working hypotheses and assumptions that provide an acceptable description of a system for the intended purpose. Because the TSPA process deals with future outcomes and includes uncertainty in both process descriptions and parameter values, there may be several ACMs that provide reasonable descriptions of a particular system or subsystem. Considering ACMs helps to build confidence that plausible changes in modeling assumptions or simplifications will not change conclusions regarding subsystem and total system performance. Also, ACMs are used to ensure that the nominal model adequately captures the range of plausible and reasonable uncertainty in the conceptual model of the repository system. Each model component and submodel discussion in Section 6.3 includes a summary evaluation of ACMs.

1.2.5 Configuration Management for the TSPA-LA Model

The development of the TSPA-LA Model required organization, control, and accountability. Configuration control was implemented for software, input parameter values, and model architecture. The result is enhanced transparency and traceability for the TSPA-LA Model.

A number of software codes were implemented to support the development of the TSPA-LA Model. Some of these codes were used to provide supporting information and some codes were directly implemented in the TSPA-LA Model using the GoldSim simulation software (GoldSim V. 9.60.100, software tracking number (STN): 10344-9.60-01 [DIRS 181903]). Supporting software codes, including process models, were developed and operated externally before running the TSPA-LA Model. Software codes directly implemented in the TSPA-LA

Model are generally referred to as abstractions and are run within the TSPA-LA Model. All software codes used to support the TSPA-LA Model are qualified and are under configuration control through Software Configuration Management (SCM) per IM-PRO-003, *Software Management*. Each qualified code is in SCM and is uniquely identified with a tracking number. The SCM database also includes information on the software name, version, hardware platform, and operating system under which the code was qualified. All software documentation, including the software media, is linked to this tracking number.

Input parameter values are controlled through the TSPA Input Database. The database supports the TSPA-LA Model by providing the parameter values and distributions necessary for the PA analysis of the repository. The TSPA Input Database categorizes, stores, and retrieves fixed and distributed values of the TSPA-LA Model parameters, and allows qualified, authorized analysts to review and update the values. The TSPA Input Database has strict user controls, featuring read and write access and audit trails that ensure the security, integrity, and traceability of the information used in the TSPA-LA Model analyses.

The TSPA-LA Model integrates several model components and submodels to simulate the performance of the repository. A numerical representation is used to implement the TSPA-LA Model with GoldSim software, which was developed by GoldSim Technology Group (GoldSim V.9.60.100, STN: 10344-9.60-01 [DIRS 181903]). The inputs used by this numerical representation of the TSPA-LA Model are obtained from controlled sources maintained by the Office of Civilian Radioactive Waste Management (OCRWM) data and information systems, such as OCRWM Program Documents, the Technical Data Management System (TDMS), the Technical Information Center, or other available sources such as NRC Proposed Rule 10 CFR Part 63 ([DIRS 178394] and [DIRS 180319]).

The TSPA-LA Model was designed and developed to run in a reasonable time on readily available computer hardware, using appropriate software. However, the size and complexity of the TSPA-LA Model makes it subject to some hardware limitations, including limiting the number of realizations that can be performed. The TSPA-LA Model was tested and provided stable results that met the validation criteria in the areas of statistical and temporal stability, spatial variability, and discretization.

The probabilistic, multiple-realization requirement necessitates that the hardware configuration has several hundred nodes. Each node is a separate processor capable of running one realization of the TSPA-LA Model. Each individual node, or central processing unit, was purchased with the largest hardware, with 3.2 gigahertz (GHz) processor speed, 3 or 4 gigabytes (GB) of random access memory (RAM) per processor, and high-speed hard drives to access virtual memory. The TSPA-LA Model uses individual central processing units with 32-bit Intel Xeon processors, which have a maximum allowable process size of 3 GB using the flexible 32-bit Windows 2003 operating system. The UZ Transport Submodel was designed to maximize the use of the 3 GB process size. More information on the hardware platform for the TSPA-LA Model is provided in Section 3.0.

The TSPA-LA Model handles both the multiple-realization requirement and the maximum size of individual coupled submodels. The GoldSim software (V. 9.60.100, STN: 10344-9.60-01 [DIRS 181903]) fulfilled all of these requirements, having an efficient solver that minimized its run time for each individual realization. The Monte Carlo sampling structure in GoldSim allows the software to simultaneously run multiple realizations by distributing the realizations to individual nodes on the (approximately) 750-node TSPA-LA Model's Computational Cluster, then reassemble the results from these realizations into an ensemble result from the entire probabilistic run. Further, GoldSim acts as a driver, or integration software, that can couple other large pieces of software for those process models and submodels that were not converted to response surfaces, but are run concurrently in the TSPA-LA Model. Examples of such software include WP degradation software, UZ transport software, FEHM, seepage software (SEEPAGEDLL_LA V. 1.3, STN: 11076-1.3-00 [DIRS 180318]), and SZ transport software (SZ_CONVOLUTE V. 3.10.01, STN: 10207-3.10.01-00 [DIRS 181060]). Because of GoldSim's ability to run each submodel software in its own process space (particularly GoldSim itself and FEHM), it can maximize the use of the computer memory, subject to a soft limitation on the amount of virtual memory that should be used on any particular node (i.e., it is generally faster to run processes in 3 or 4 GB of RAM per processor than to run on the hard disk virtual memory).

1.3 YUCCA MOUNTAIN SITE DESCRIPTION

The Yucca Mountain Repository system consists of natural and engineered systems that together will ensure the safe disposal of radioactive materials. The following information is provided as a general overview of the Yucca Mountain site, giving a context for the development of the TSPA-LA Model that is discussed in detail in the remainder of this document. The understanding and analysis of FEPs relevant to postclosure performance is described in the supporting analyses that contain the abstractions used as input to the TSPA-LA Model. Detailed information on the direct inputs to the TSPA-LA Model is provided in Section 6 with full references and traceability.

The characteristics of the natural systems at Yucca Mountain that affect repository performance include climate, site geology, and site hydrogeology. The characteristics of the site geology and hydrogeology that affect repository performance include groundwater flow through the UZ and SZ, radionuclide transport, and disruptive events caused by igneous and seismic activity. This section provides a brief description of the current understanding of the Yucca Mountain natural system and the repository design. Information on Yucca Mountain site characteristics, along with descriptions of field and laboratory investigations conducted at Yucca Mountain, can be found in *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734]), which contains comprehensive descriptions of the repository site and the surrounding region.

1.3.1 Physiographic Setting and Topography

Yucca Mountain is located within a transition zone between the northern boundary of the Mojave Desert and the southern boundary of the Great Basin Desert (BSC 2004 [DIRS 169734], Section 3.2.1, and BSC 2004 [DIRS 169734], Sections 6, 7, and 8). The topography is characterized by isolated, long and narrow, roughly north-south-trending mountain ranges and broad intervening valleys (Figure 1-4). The Yucca Mountain physiography consists of steep and narrow V-shaped highland valleys that grade into flat alluvial floors in their lower reaches (BSC 2004 [DIRS 169734], Section 1.3.1).

The local topography is described in *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734], Section 7.1.3.3) and has the following characteristics. Landforms include about 5 to 10 percent ridgetops, 45 percent side slopes (including footslopes), about 45 percent terraces, and less than 5 percent active channels. The surface elevations above the repository site are approximately 1,400 m above mean sea level . Terraces and channels are located at lower elevations of the primary washes and have thinner soil cover in the upper washes and thicker soil cover further downgradient. Yucca Mountain is a generally north-to-south-trending ridge with a relatively gentle eastward slope and a steep, westward facing escarpment. The topography in the Yucca Mountain vicinity is shaped by erosional processes on the eastward-sloping ridge of the mountain and along faults and fault scarps that have created a series of washes downcut to varying degrees into different bedrock layers. Slopes are locally steep on the west-facing escarpments eroded along the faults and in some of the valleys that cut into the more gentler eastward-facing dip slopes. As described in the *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734], Section 7.1.1.1), narrow valleys and ravines are cut in bedrock; wider valleys are covered by alluvial deposits, with terraces cut by intermittent streams. Locally, small sandy alluvial fans extend down the lower slopes and spread out on the valley floors. East of the Yucca Mountain crest, drainage is into Fortymile Wash. West of the crest, streams flow southwestward down fault-controlled canyons and discharge into Crater Flat (Figure 1-4). The topography is different to the south and north of Drill Hole Wash. The washes south of Drill Hole Wash trend eastward, are relatively short (less than 2 km), and have erosional channels with gently sloping sides (Figure 1-5). The washes north of Drill Hole Wash trend northwest and are relatively longer (3 to 4 km) because they are controlled by fault features and have steeper side slopes.

1.3.2 Climate and Precipitation

In general, the present-day Nevada climate is characterized as semiarid to arid, with dry winds and low precipitation. The Pacific side of the mountain system to the west of Nevada causes a rain shadow effect, which in turn, causes moisture-loaded winds traveling east from the Pacific Ocean to rise, cool, and drop precipitation on the Pacific mountain system. The climatic factors affecting water-transport processes in the UZ at Yucca Mountain are solar radiation flux, diurnal and seasonal temperature cycles, relative humidity, and precipitation, in the form of either rain or snow, as well as extended periods of drought. The Yucca Mountain Project environmental program collected site meteorological data using a network of nine automated weather stations (BSC 2004 [DIRS 169734], Section 7.1.3.2). Current climatic conditions for the site and the Yucca Mountain region are discussed in detail in *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734], Section 6.3).

The analysis of data from 114 weather stations measuring precipitation in the Yucca Mountain region, providing at least eight years of complete records, indicates a strong positive correlation between average annual precipitation and station elevation (BSC 2004 [DIRS 169734], Figure 7-7). These results indicate that the zones of maximum precipitation are likely to correspond to the zones of higher elevations in the mountain ranges. Average annual precipitation over the area of the Nevada Test Site ranges from a maximum of 370 mm in the Belted Range to a minimum of 100 mm in the Amargosa Desert. Annual precipitation in the Yucca Mountain vicinity ranges from a minimum of about 100 mm at low elevations along the southern boundary of the repository area to a maximum in excess of 300 mm at high elevations in the north (BSC 2004 [DIRS 169734], Figure 7-6).

1.3.3 Geology

1.3.3.1 Surficial Deposits

The dominant surficial deposits in the general vicinity of Yucca Mountain are fluvial sediments and fluvial debris-flow deposits found in basins, washes, and alluvial fans. These deposits have varying degrees of soil development and thickness and have a gravelly texture, with rock fragments constituting between 20 and 80 percent of the total volume (BSC 2004 [DIRS 169734], Section 3.3.7.2). The deposits range from 100-m thick in the valleys to less than 30-m thick in the mouths of the washes. Halfway up the washes, alluvial fill generally is less than 15-m deep in the center of the channels and well-developed, cemented, calcium-carbonate soil horizons are common. On the more stable surfaces, generally on the ridgetops, soils are 0.5- to 2-m thick with a high clay content. Overall, the thickness of surficial deposits was classified into 4 categories: 0 to less than 0.5 m, 0.5 m to less than 3.0 m, 3.0 m to less than 6.0 m, and greater than or equal to 6.0 m, which encompass about 50 percent, 5 percent, 5 percent, and 40 percent of the site area, respectively (BSC 2004 [DIRS 169734], Section 3.3.7). Soil thickness tends to be well correlated to local topography, with the upland areas generally having thin soils and the lower washes and alluvial fans having thicker soils (surficial materials). The deeper deposits are present on the shallower slopes of the ridges, in washes, and underlying alluvial fans, whereas the deposits on the steeper side slopes, if present, consist of colluvium from rock slides. For the infiltration modeling, mapped surficial, unconsolidated deposits were reconfigured into five surficial soil classes based on differences in soil texture (SNL 2007 [DIRS 182145], Sec. 6.5.2.4). *Simulation of Net Infiltration for Present-Day and Potential Future Climates* (SNL 2007 [DIRS 182145], Tables 6.5.2.4-2 and 6.5.2.4-3) describe the five soil classes and their nominal soil depths as follows: Class 1, Very deep soils, 95 m; Class 2, Moderately deep soils, 16.47 m; Class 3, Intermediate depth soils, 3.26 m; Class 4, Shallow soils, 0.25 m; and Class 5, Exposed bedrock, 0 m. Soil types account for bare rock and disturbed ground, consistent with the geologic mapping. Soil storage capacity is determined mostly by soil thickness and porosity. Soil porosity and permeability, along with various other hydrologic properties, such as residual water content and field capacity, can be correlated to soil type (BSC 2004 [DIRS 169734], Section 7.1.3.4).

The maximum erosion during the first 10,000 years after repository closure is expected to be on the order of centimeters (BSC 2004 [DIRS 169734], Section 3.4.6), which is within the range of existing surface elevation irregularities, and would not affect the processes in the hundreds of meters of UZ at Yucca Mountain. Similar conditions can be expected to be in effect throughout the one-million-year period of geologic stability (NRC Proposed Rule 10 CFR 63.302 [DIRS 178394]). Therefore, the effects of soil erosion on infiltration are considered negligible and are reasonably excluded from the TSPA-LA Model calculations (Data Tracking Number (DTN): MO0508SEPFEPLA.002_R0 [DIRS 175064]).

1.3.3.2 Bedrock Geology

Yucca Mountain is an uplifted, block-faulted ridge of alternating layers of welded and nonwelded volcanic tuffs of Miocene age. The major Yucca Mountain geologic units are the volcanic tuff formations of the Paintbrush Group (Tp), the Calico Hills Formation (Tac), and the Crater Flat Group (Tc). The lithostratigraphic nomenclature divides the Paintbrush Group into the Tiva Canyon (Tpc), Yucca Mountain (Tpy), Pah Canyon (Tpp), and Topopah Spring (Tpt) tuffs. The Crater Flat Group is divided into the Prow Pass (Tcp), Bullfrog (Tcb), and Tram (Tct) tuffs. For the purposes of hydrogeologic studies, including infiltration, a separate stratigraphic nomenclature was developed based on the degree of welding and the distribution of the hydrologic properties of the hydrogeologic units (BSC 2004 [DIRS 169734], Tables 3-1, 3-5, and 7-1). The main geologic units are divided into the Tiva Canyon welded (TCw), the Paintbrush nonwelded (PTn) (consisting primarily of the Yucca Mountain and Pah Canyon members and the interbedded tuffs), the Topopah Spring welded (TSw), the Calico Hills nonwelded (CHn), and the Crater Flat undifferentiated (CFu) units (Ortiz et al. 1985 [DIRS 101280]). Figure 1-6 shows the spatial relationship of the geologic units of the UZ in both perspective and east-west cross-sectional views.

1.3.3.3 Tectonics

1.3.3.3.1 Tectonic Setting

Tectonic setting refers to the geologic framework or structural configuration of the different rock masses in the Yucca Mountain vicinity. The overall tectonic setting of the Great Basin physiographic province generally consists of fault-bounded basins and mountain ranges (including Yucca Mountain) that have been modified by volcanic activity during the past 15 million years. Typically, faults in this setting include normal and strike-slip faults that reflect the extensional deformation caused by the tectonic interactions of crustal plates at the western margin of the North American continent. Studies of the extensional tectonics in the central Basin and Range tectonic province (Snow and Wernicke 2000 [DIRS 159400]) conclude that approximately 250 to 300 km of extension have occurred by a west-northwest motion of the Sierra Nevada block away from the Colorado Plateau, at rates initially as great as 2 cm/yr, and at 1.5 to 1 cm/yr during the last 5 million years. Research suggests that most of the current extension, as indicated by strain measurements and seismicity, is concentrated along the eastern and western margins of the Basin and Range tectonic province (Thatcher et al. 1999 [DIRS 119053]; Martinez et al. 1998 [DIRS 159031]).

1.3.3.3.2 Structural Geology

The structural geology of Yucca Mountain and its vicinity (BSC 2004 [DIRS 169734], Section 3.5) is dominated by a series of north-striking normal faults (Figure 1-7), along which Tertiary volcanic rocks were tilted and displaced hundreds of meters. Movement occurred during a period of extensional deformation in the middle-to-late Miocene time, but has continued at a low level into the Quaternary Period, which consists of the last 1.8 million years before the present. These faults extend through the Yucca Mountain vicinity and divide the site area into several blocks, each of which is further deformed by minor faults. Block-bounding faults within the Yucca Mountain site area are spaced from 1 to 6 km apart and include, from east to west, the Paintbrush Canyon, Bow Ridge, Solitario Canyon-Iron Ridge, Fatigue Wash, and Windy Wash faults (BSC 2004 [DIRS 169734], Section 3.5, Figures 1-7 and 1-8), which commonly dip from 50° to 80° to the west. Displacements along these block-bounding faults are mainly dip-slip, down-to-the-west, with subordinate strike-slip or oblique-slip components of movement exhibited along some faults. Numerous intrablock faults occur within the individual structural blocks, representing local adjustments in response to the stress created, for the most part, by the large displacements that took place along the block boundaries (BSC 2004 [DIRS 169734], Section 3.5).

1.3.3.3.3 Volcanism

Two types of volcanism have occurred in the Yucca Mountain region. An early phase of Miocene silicic volcanism in the southwestern Nevada volcanic field culminated between 11.8 and 12.4 million years ago with the eruption of 4 voluminous ash-flow tuffs of about 1,000 km^3 each (Sawyer et al. 1994 [DIRS 100075], pp. 1311 and 1312). One of the silicic ash-flow tuffs that erupted from the Timber Mountain Caldera Complex (Figure 1-9) is the Topopah Spring Tuff, which forms the horizon that will be used for waste emplacement. Yucca Mountain is an uplifted, erosional remnant of these voluminous ash-flow tuff deposits.

The early caldera-forming, silicic volcanism was approximately coincident with the major period of crustal extension, which occurred primarily between 13 and 9 million years ago (Sawyer et al. 1994 [DIRS 100075], pp. 1314 and 1316). The onset of basaltic volcanism in the Yucca Mountain region occurred as extension rates waned during the latter part of the caldera-forming period of silicic volcanism. Small-volume basaltic volcanism continued into the Quaternary Period. In terms of eruption volume, the 15-million year history of volcanism in the Yucca Mountain region is viewed as a magmatic system that peaked between 13 and 11 million years ago, with the eruption of more than 5,000 km^3 of ash-flow tuffs. Following this peak of eruptive activity, volcanism has been in decline, characterized by eruptions of relatively minor volumes of basalt since 11 million years ago (BSC 2004 [DIRS 169989], Section 6.2). Approximately 99.9 percent of the volume of the southwestern Nevada volcanic field erupted before about 7.5 million years ago, culminating with the eruption of tuffs from the Stonewall Mountain volcanic center, which is the last active caldera system of the southwestern Nevada volcanic field. The last 0.1 percent of eruptive volume of the volcanic field consists of basalt that erupted since 7.5 million years ago (BSC 2004 [DIRS 169989], Section 6.2). Considered in terms of total eruption volume, frequency of eruptions, and duration of volcanism, basaltic volcanic activity in the Yucca Mountain region comprises one of the least active basaltic volcanic fields in the western United States (e.g., *Synthesis of Volcanism Studies for the Yucca Mountain Site Characterization Project* (CRWMS M&O 1998 [DIRS 105347], Chapter 2)).

Post-caldera basalts in the Yucca Mountain region can be divided into 2 episodes: Miocene eruptions, between approximately 9 and 7.3 million years before present, and post-Miocene eruptions, between approximately 4.8 and 0.08 million years ago. The time interval of about 2.5 million years between these episodes is the longest hiatus of basaltic eruptive activity in the Yucca Mountain region during the last 9 million years (CRWMS M&O 1998 [DIRS 105347], Chapter 2). This eruptive hiatus also marks a distinct shift in the locus of post-caldera basaltic volcanism to the southwest in the Yucca Mountain region (BSC 2004 [DIRS 169989], Section 6.2). Thus, the Miocene basalts and post-Miocene basalts are both temporally and spatially distinct.

1.3.4 Hydrogeology

1.3.4.1 Surface Hydrology

Yucca Mountain is located in the Amargosa River drainage basin, which is the major tributary drainage area to Death Valley (Figure 1-4). Streamflow from Yucca Mountain can extend from local drainages to the Amargosa River and then to Death Valley. The Amargosa River and its tributaries are ephemeral streams that are dry most of the time, with surface water flow rarely occurring in direct response to precipitation. In some cases, groundwater discharges at springs in stream channels. During episodic flooding, flow occurs along the Amargosa River, filling much of Death Valley to depths of 0.3 m or more (Miller 1977 [DIRS 105462], p. 18). During periods in which the climate has been cooler and wetter, such as 140,000 to 175,000 years ago, Death Valley was filled with water to depths of 175 m (BSC 2004 [DIRS 170002], Section 6.2, p. 6-6). The entire Death Valley drainage basin and several closed drainage basins are hydrologically interconnected through the groundwater system (D'Agnese et al. 1997 [DIRS 100131], Figure 9, pp. 20 and 22). About 10,000 km^2 of watershed area drain directly into Death Valley (Miller 1977 [DIRS 105462], p. 18). The Amargosa River drains almost 9,100 km^2 north and east of Death Valley. Like the streams, the playas are mainly ephemeral and contain water only after heavy runoff periods, and perennial flow is only observed downgradient from spring discharges and around the margins of playas and saltpans, where the groundwater discharges to the land surface.

1.3.4.2 Groundwater Hydrology

Yucca Mountain is located within the larger Death Valley Regional Groundwater System (Figure 1-4). The groundwater flow system of the Death Valley region is complex, involving many local groundwater systems. There is groundwater movement between aquifers in some areas. In other areas, low-permeability confining units support artesian conditions. The groundwater below Yucca Mountain and in the surrounding region flows generally south toward discharge areas in the Amargosa Desert and Death Valley. The area around Yucca Mountain is in the central subregion of the Death Valley Regional Groundwater System, which consists of the Pahute Mesa-Oasis Valley, Ash Meadows, and Alkali Flat-Furnace Creek groundwater basins. The primary sources of groundwater recharge to the regional system are infiltration on Pahute Mesa, Rainier Mesa, Timber Mountain, and Shoshone Mountain to the north, and the Grapevine and Funeral Mountains to the south (Figure 1-4). Recharge in the immediate Yucca Mountain vicinity is low, consisting of water reaching Fortymile Wash (Figure 1-4), as well as precipitation that infiltrates into the subsurface (BSC 2004 [DIRS 169734], Section 7.1.2).

1.4 DESIGN OF YUCCA MOUNTAIN REPOSITORY SUBSURFACE FACILITIES

Following is a description of the design and layout of the repository subsurface facility and engineered barrier system (EBS). Descriptions of the repository subsurface facility are found in *Total System Performance Assessment Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179394]) and in *Total System Performance Assessment Data Input Package for Requirements Analysis for Subsurface Facilities* (SNL 2007 [DIRS 179466]).

1.4.1 Repository Layout

The layout of the subsurface facility is illustrated on Figure 1-10 (SNL 2007 [DIRS 179466], Table 4-1, Parameter Number 01-02). The emplacement drifts will be excavated using a tunnel boring machine to a diameter of 5.5 m; with a nominal length of 600 m (actual lengths will range from 355 to 808 m). Emplacement drifts will be excavated in a sequence of 4 panels, which will contain 70,000 metric tons of heavy metal waste. Emplacement drifts will be arranged with a uniform spacing of 81 m between their centerlines. The repository design used in the TSPA-LA Model calls for approximately 100 WPs to be placed in a single emplacement drift with a nominal length of 600 m. There is an area in the southern section of the repository that will be constructed to allow for contingencies during waste emplacement. The repository's host-rock units contain both lithophysal and nonlithophysal units. The lithophysal rock units are characterized by numerous cavities (lithophysae), which result in high porosities. The lithophysal rock units are highly fractured and the fractures have short trace lengths. In contrast, the nonlithophysal rock units are characterized by few cavities, lower porosities, and fractures with generally longer trace lengths. Approximately 80 to 85 percent of the emplacement drift area will be excavated in lithophysal units, and 15 to 20 percent will be excavated in nonlithophysal units of the repository host horizon (SNL 2007 [DIRS 179466], Table 4-1, Parameter Number 01-01).

1.4.2 Features of the Engineered Barrier System

The subsurface facility system includes ground support, such as rock bolts, steel liner, cement, and wire mesh. The EBS design (SNL 2007 [DIRS 179354], Figure 4-1) includes a DS, a two-layer WP, a corrosion-resistant emplacement pallet (made of Alloy 22 and stainless steel on which the WPs will be placed), and an invert, consisting of a steel support structure and crushed, welded tuff, at the base of the emplacement drifts. The TSPA-LA Model analysis of the EBS does not include the degradation of the subsurface facility system's ground-support material. Figure 1-11 presents a cross-section illustration of an emplacement drift and the major components of the EBS. The following provides a more detailed description of each of the EBS components and repository thermal loading.

1.4.2.1 Drip Shield

The DSs will be composed of a corrosion-resistant titanium alloy. The function of the DSs is to reduce the effect of rockfall and dripping on the WPs. The DSs are designed to link together, forming a single continuous barrier for the entire length of the emplacement drifts. The DSs will be fabricated from Titanium Grade 7 plates, with Titanium Grade 29 for structural support. The base plates will be composed of Alloy 22 to prevent direct contact between titanium and the steel members of the invert.

1.4.2.2 Waste Package

WPs will consist of an outer layer and an inner layer (Figure 1-11). The outer layer is 25-mm thick corrosion-resistant Alloy 22. The WPs will be treated to minimize the possibility of SCC, and the outer closure weld will be stress mitigated. The inner layer is 50-mm thick stainless steel and serves 3 functions. First, the inner layer provides structural strength to resist rockfall, to support the internal waste form components, to allow the WPs to be supported by the emplacement pallets, and to facilitate handling. Second, the inner layer provides radiation shielding to reduce the exterior surface contact dose rate. Third, because of sorption of radionuclides on corrosion products from the degradation of the inner layer, it acts as a limited containment part of the EBS barrier for the radioactive waste inside the WPs. The inner layer is not considered to be a barrier to flow. In order to calculate radionuclide transport through the WPs, the TSPA-LA Model uses the transportation, aging, and disposal (TAD) canister with 21-PWR fuel assemblies as the representative CSNF WP, and the 5-DHLW/DOE Long WP as the representative configuration for the co-disposed (CDSP) WPs that contain both DOE spent nuclear fuel (DSNF) and HLW glass. These CSNF and CDSP WPs are planned to be the most common two types of WPs in the repository (SNL 2007 [DIRS 177407], Section 6.3.3.1).

1.4.2.3 Emplacement Pallet

An emplacement pallet will support each WP (Figure 1-11). The emplacement pallets are designed to prevent the WPs from coming in contact with the invert of the emplacement drifts and, therefore, prevent direct exposure to invert moisture or materials that may induce accelerated corrosion of the WPs. The material supporting the WPs will consist of Alloy 22, providing long-term corrosion resistance and an identical material in contact with the outer surfaces of the WPs. To reduce the possibility of SCC, the emplacement pallets will also be annealed to remove stresses from welding and fabrication.

1.4.2.4 Invert

The invert will provide support for the WP emplacement pallets and the DSs. The invert consists of two components: a steel invert structure and a crushed tuff fill. The granular crushed tuff will be composed of crushed welded tuff produced from the excavation of the repository's underground openings with the tunnel boring machines, and will be placed in and around the steel invert structure to an elevation just below the top of the longitudinal and transverse support beams. The crushed tuff will be compacted to prevent long-term settlement.

1.4.2.5 Waste Form

SNF consists of fuel removed from nuclear reactors after its useful heat-generating capacity has been spent. The TSPA-LA Model analyzes the disposal of WPs containing CSNF and CDSP WPs, containing both DSNF and HLW. CSNF consists primarily of uranium oxide, some of which has been enriched with surplus plutonium to create a mixed-oxide fuel (MOX). DSNF is fuel associated with DOE's defense programs and research and development programs. The majority of DSNF consists of a uranium-metal compound SNF with zirconium cladding, which accounts for approximately 86 percent of the mass of the DSNF inventory . However, there are 11 categories of DSNF representing a variety of uranium-based waste forms (Sections 7.5.2 to 7.5.4). Naval spent nuclear fuel, a category of DSNF, is classified material and, as such, cannot be included in the unclassified TSPA-LA Model. Naval fuel is represented as CSNF for modeling purposes (Section 7.5.2). HLW consists of by-products of nuclear reactions, material generated during fuel preparation and reprocessing, and sludges and residues recovered from nuclear-waste storage tanks. HLW will be mixed and solidified in a high-temperature, borosilicate glass for storage in stainless-steel canisters. CDSP WPs typically contain five HLW canisters surrounding one DSNF canister.

Following breaching of the CSNF WPs and CDSP WPs and exposure of the fuel, the waste forms will be subject to aqueous dissolution at various rates followed by release of radionuclides to the EBS.

1.4.2.6 Waste Form Cladding

Nuclear fuel generally consists of stacked pellets of uranium-based fuel encased in a metallic protective cladding. However, for the PA analyses, the TSPA-LA Model assumes that CSNF cladding is failed at the time the WPs are breached. In addition, DSNF cladding is in poor condition and is considered to be failed upon receipt. Therefore, the TSPA-LA Model does not take credit for spent-fuel cladding.

1.4.2.7 Emplacement Drift

The nuclear waste will be placed in 5.5-m diameter, circular emplacement drifts excavated with tunnel boring machines. The drifts will serve to enhance the role of the natural barriers and the EBS due to two processes: (1) the formation of a capillary barrier at the drifts' walls that will be active during the thermal and ambient postclosure periods, and (2) the formation of a dry-out zone helping to prevent percolation from reaching the repository during the thermal period. The effectiveness of these processes depends on the strength of the capillary pressure in the fractures close to the drift, the host rock's permeability close to the drifts, the local percolation flux above the drifts, the temperature of the rock near the drifts' walls, and the shape of the drift openings.

1.4.2.8 Internal Waste Package Components

The WPs will have internal steel components consisting primarily of carbon-steel basket guides and basket tubes, steel canisters for HLW and DSNF, and stainless-steel inner WP liner. All these internal steel components are expected to degrade to iron oxyhydroxides upon exposure to water and repository atmospheric conditions following WP failure. These degradation products could potentially sorb radionuclides released from the degradation of the waste forms.

1.4.3 Waste Emplacement Approach

WPs will be placed in the emplacement drifts in a line-load configuration with a WP-to-WP spacing of approximately 10 cm, and a line-averaged heat load of 1.45 kW/m per 12 WPs (SNL 2007 [DIRS 179354], Table 4-4, Parameter Numbers 05-02 and 05-03). Preclosure ventilation will be activated for at least 50 years from the start of waste emplacement.

1.5 GENERAL DESCRIPTION OF THE TSPA-LA MODEL

The development of the TSPA-LA Model began with the identification and screening of all FEPs that could affect the repository (Section 1.2.1). Appendix I contains additional information on all FEPs that have been included in the TSPA-LA Model. This information provides a mapping between the FEPs documentation, the TSPA-LA Model, and the associated GoldSim software (GoldSim V. 9.60.100, STN: 10344-9.60-01 [DIRS 181903]) model file. The FEPs that were screened in were used to develop the scenario classes for the TSPA-LA Model analyses (Section 1.2.2). Figure 1-3 is a schematic representation of the development of the TSPA-LA Model. The Figure illustrates how the TSPA-LA Model, for analysis purposes, divides the repository system into individual model components. Each individual model component represents a major process or set of processes of the total repository system. Figure 1-3 indicates these model component areas as well as the scenario classes that are included in analyses of repository performance.

GoldSim software (GoldSim V. 9.60.100, STN: 10344-9.60-01 [DIRS 181903]) integrates the model components and submodels of the TSPA-LA Model allowing simulation of repository performance for each realization of uncertain parameters. GoldSim manages the flow of information between and among the external process models, the model components and submodels, and the abstractions provided to the TSPA-LA Model. A separate software code, EXDOC 2.0, uses GoldSim results to compute mean and median dose. The principal model components of the TSPA-LA Model are described in the following sections.

1.5.1 Model Components and Modeling Case for the Nominal Scenario Class

The TSPA-LA Model is based on the Nominal Scenario Class, which incorporates all expected FEPs to describe the most likely fundamental processes at work under ambient conditions, as well as possible changes to those processes after repository closure. The Nominal Scenario Class represents the most likely FEPs under the expected natural conditions prevailing at the repository. The Nominal Scenario Class describes WP failure during expected repository performance without the occurrence of early failure of EBS components or of disruptive events. The Nominal Scenario Class includes a single modeling case, the Nominal Modeling Case, that addresses FEPs that describe WP degradation due to corrosion mechanisms including general corrosion, SCC, localized corrosion, and MIC. The TSPA-LA Model components for the Nominal Modeling Case are the nominal modeling components, namely:

- UZ Flow
- EBS Environment
- WP and DS Degradation
- Waste Form Degradation and Mobilization
- EBS Flow and Transport
- UZ Transport
- SZ Flow and Transport
- Biosphere.

1.5.1.1 Unsaturated Zone Flow

The UZ Flow Model Component defines the temporal and spatial distribution of water flow from the ground surface through the unsaturated tuffs above and below the repository horizon and the temporal and spatial distribution of water dripping into the waste emplacement drifts. The UZ Flow Model Component of the TSPA-LA Model integrates five processes that contribute to flow in the UZ. These processes include: climate-induced precipitation, infiltration, mountain-scale UZ flow, drift seepage, and drift-scale coupled processes. Figure 1-12 provides a conceptual illustration of the Yucca Mountain mountain-scale flow processes. The UZ Flow Model Component provides a representation of the hydrogeologic processes above and below the repository. Water that reaches the repository horizon has its source in precipitation at the land surface above the repository. This precipitation occurs in the form of rainfall and snow. The temporal variability in precipitation that occurs is included in the TSPA-LA Model by specifying four successive climate states: present-day climate and three future climate states (Figure 1-13). The climate from 10,000 years after repository closure to the period of geologic stability is based on specifications regarding deep percolation rates described in NRC Proposed Rule 10 CFR 63.342(c)(2) [DIRS 178394] (Sections 1.1.1 and 1.6.1).

1.5.1.2 Engineered Barrier System Environment

The EBS Environment Model Component includes the EBS mountain-scale thermal-hydrology and the EBS chemical environments within the emplacement drifts. These environments are important to repository performance because they help determine the degradation rates of EBS components, quantities and species of mobilized radionuclides, and transport of radionuclides and fluids through the repository and drifts, and their release into the UZ below the repository. Figure 1-12 shows the position of the repository drifts and WPs with respect to the flow system within Yucca Mountain. The percolation moving into the repository environment will be affected by heat from the emplaced waste. The waste heat and geochemical processes and conditions will determine the EBS chemical environment.

1.5.1.3 Waste Package and Drip Shield Degradation

Together, the WPs and DSs are the key engineered components of the EBS (Figure 1-14). The WP and DS Degradation Model Component describes the degradation of the WPs and DSs as a function of time, presence of water, and repository location. The WP and DS Degradation Model Component is described in Section 6.3.5. The WP and DS Degradation Model Component includes the implementation of WAPDEG.DLL (WAPDEG V. 4.07 [DIRS 181774]) within GoldSim and supporting submodel implementations. The WP and DS Degradation Model Component accounts for the following degradation processes: general corrosion of the DSs; general corrosion and localized corrosion of the outer surfaces of the WPs; SCC of the WPs; MIC on the outer surfaces of the WPs; and early DS and WP failure.

1.5.1.4 Waste Form Degradation and Mobilization

The Waste Form Degradation and Mobilization Model Component establishes the radionuclide inventories for representative CSNF and CDSP WPs (Figure 1-15) using the radionuclide inventories for the CSNF, DSNF, and HLW waste forms, and then calculates the rates of degradation of these waste forms. Figure 1-16 provides an overview of the mechanisms included in the Waste Form Degradation and Mobilization Model Component, as well as the concentrations of radionuclides released from the CSNF waste forms to the EBS Transport Submodel. The Waste Form Degradation and Mobilization Model Component accounts for the following processes and conditions: in-package water chemistry, matrix degradation rates for CSNF, DSNF, and HLW waste forms, radionuclide solubilities, and the types and concentrations of waste form and in-drift colloids.

1.5.1.5 Engineered Barrier System Flow and Transport

The EBS Flow and Transport Model Component calculates the rate of radionuclide release from the EBS to the UZ. This quantity is determined by seepage into the emplacement drifts, condensation on the drift walls, WP and DS degradation, the presence of water films on in-package internals, and the EBS thermal-hydrologic (TH) environment (Figure 1-17). The EBS Flow and Transport Model Component accounts for the following processes: the rate of water flow through the EBS, diffusive and advective transport, sorption, and colloid-facilitated transport.

1.5.1.6 Unsaturated Zone Transport

The UZ Radionuclide Transport Model Component describes the migration of radionuclides from the EBS of the repository, through the UZ, to the water table. Consistent with the Mountain-Scale UZ Flow Submodel, the conceptual model for UZ transport (Figure 1-18) uses a dual-continuum representation to couple advective and diffusive transport through fracture and matrix continua. The UZ Transport Model Component accounts for the following processes: advection, dispersion, matrix diffusion, sorption, colloid facilitated transport (retardation, filtration, and size exclusion), radioactive decay and ingrowth, climate change, and water table rise.

1.5.1.7 Saturated Zone Flow and Transport

The SZ Flow and Transport Model Component evaluates the transport of radionuclides from their introduction at the water table below the repository to the regulatory boundary 18 km downgradient from the Yucca Mountain Repository (Figure 1-19). Radionuclides move through the SZ either as solutes or sorbed to colloids. The SZ Flow and Transport Model Component accounts for the following processes: advection and dispersion, matrix diffusion, colloid retardation and exclusion, radioactive decay and ingrowth, sorption, climate change, and water table rise.

1.5.1.8 Biosphere

The Biosphere Model Component evaluates radionuclide transport in the biosphere and the resulting exposure of the RMEI (NRC Proposed Rule 10 CFR 63.312 [DIRS 180319]) for releases of radioactive material after closure of the repository (Figure 1-19). The Biosphere Model Component analyzes two dominant mechanisms of radionuclide release to the biosphere: (1) release through the SZ via groundwater, and (2) release through the air by ash dispersal from a volcanic eruption. These two release mechanisms correspond to the two modes by which radionuclides may be introduced into the biosphere.

1.5.2 Model Components and Modeling Cases for the Early Failure Scenario Class

The Early Failure Scenario Class addresses FEPs that describe WP failures due to materials and/or manufacturing defects or pre-emplacement operations and practices that could affect the performance of the EBS. The Early Failure Modeling Cases address FEPs that describe the potential for DS and WP early failure that could affect repository performance in the absence of disruptive events. The Drip Shield EF Modeling Case analyzes the possibility that DSs could fail prematurely, thus failing to protect the underlying WPs from seepage and possible localized corrosion. The Waste Package EF Modeling Case analyzes WPs that fail prematurely due to material defects, manufacturing errors, or pre-emplacement operations and practices, such as improper heat treatment or welding flaws that could affect WP performance and longevity. The TSPA-LA Model components for the Early Failure Scenario Class modeling cases are the nominal modeling components, namely:

- UZ Flow
- EBS Environment
- WP and DS Degradation
- Waste Form Degradation and Mobilization
- EBS Flow and Transport
- UZ Transport
- SZ Flow and Transport
- Biosphere.

The Early Failure FEPs are addressed by specifying initial conditions for the TSPA-LA Model, which represent WPs and/or DSs that experience early failure.

1.5.3 Model Components and Modeling Cases for the Igneous Scenario Class

The Igneous Scenario Class addresses FEPs that describe igneous activity that could affect repository performance. The Igneous Scenario Class includes the Igneous Intrusion Modeling Case that addresses the FEPs for the unlikely possibility that magma, in the form of a dike, could intrude into the repository and disrupt expected repository performance. The Igneous Scenario Class also includes a Volcanic Eruption Modeling Case that addresses FEPs that describe a volcanic conduit that invades the repository, destroys WPs, and erupts at the land surface. The volcanic eruption disperses volcanic tephra and entrained waste under atmospheric conditions and deposits the contaminated tephra on land surfaces where the contaminated tephra becomes subject to redistribution by soil and near-surface hydrogeologic processes.

1.5.3.1 Igneous Intrusion Modeling Case

The Igneous Intrusion Modeling Case assumes that a dike intersects the repository and destroys all DSs and WPs, exposing the waste forms to percolating water and mobilizing radionuclides that may then be transported out of the repository and down through the UZ to the SZ, and then transported to the accessible environment. The TSPA-LA Model uses the following model components to calculate total system performance for the Igneous Intrusion Modeling Case:

- UZ Flow
- EBS Environment
- WP and DS Degradation
- Waste Form Degradation and Mobilization
- EBS Flow and Transport
- UZ Transport
- SZ Flow and Transport
- Biosphere.

Prior to the time of the first intrusion, the TSPA-LA Model for the Igneous Intrusion Modeling Case is the same as the model for the Nominal Modeling Case. The TSPA-LA Model changes the representation of the EBS components (WPs and DSs) at the time of the first intrusion to represent damage to the EBS caused by the intrusion of magma. The TSPA-LA Model assumes that the entire repository is damaged at the time of the first intrusion and that subsequent intrusions cause no significant additional damage.

1.5.3.2 Volcanic Eruption Modeling Case

The Volcanic Eruption Modeling Case represents the fraction of igneous intrusions in which the conduit for a volcanic eruption also intersects a repository drift. In this case, waste from WPs is transported to the land surface through one or more eruptive conduits, and tephra and entrained waste are discharged into the atmosphere, transported by wind currents, and deposited at land surface. The Volcanic Eruption Modeling Case also evaluates the fluvial and eolian redistribution of contaminated tephra deposited on the land surface. The TSPA-LA Model uses the following processes and model components to calculate repository system performance for the Volcanic Eruption Modeling Case:

- Volcanic interaction with the repository
- Atmospheric transport
- Tephra redistribution
- Biosphere.

The TSPA-LA Model does not include any nominal processes other than radionuclide decay prior to the occurrence of an eruptive event.

1.5.4 Model Components and Modeling Cases for the Seismic Scenario Class

The Seismic Scenario Class evaluates repository performance in the event of seismic activity capable of disrupting repository emplacement drifts and the engineered components of the EBS through ground motion and fault displacement. The Seismic Scenario Class includes damage to DSs and WPs as a function of ground motion or fault displacement associated with a seismic event. Radionuclides in breached WPs may be mobilized and transported out of the repository, transported through the UZ to the SZ, and then to the accessible environment. The TSPA-LA Model uses the following model components to estimate total system performance for the Seismic Scenario Class:

- UZ Flow
- EBS Environment
- WP and DS Degradation
- Waste Form Degradation and Mobilization
- EBS Flow and Transport
- UZ Transport
- SZ Flow and Transport
- Biosphere.

The Seismic Scenario Class includes two modeling cases: (1) Seismic GM Modeling Case and (2) Seismic FD Modeling Case. The Seismic GM Modeling Case addresses FEPs concerning damage due to vibratory ground motion, which include:

- Potential buckling and/or rupture of the DS due to accumulated rockfall and dynamic loading during seismic events
- Potential SCC damage and/or rupture of WPs due to seismic events
- Diffusion and/or advection of mobilized radionuclides from failed or ruptured WPs.

The Seismic FD Modeling Case addresses FEPs that describe damage due to fault displacement, including rupture of WPs and the overlying DS components. FEPs that describe localized corrosion are also included in both Seismic Modeling Cases because rupture of the DS leads to the possibility of crown-seepage induced localized corrosion of WPs.

Prior to the first seismic event, the TSPA-LA Model for the Seismic GM Modeling Case is the same as the model for the Nominal Modeling Case. After the first seismic event, rockfall may affect seepage into a drift, damage to DS components may affect seepage contacting WPs, and damage to WPs may result in radionuclide release. Rockfall and damage may accumulate as additional seismic events occur, increasing the effects on flow and transport processes. Seismic events that include fault displacement will affect an uncertain number of WPs. Subsequent fault displacement events will not increase damage to WPs already damaged by preceding fault displacement events, although additional WPs may be damaged. If a WP is damaged by a fault displacement event, the overlying DS is considered to be ruptured and is no longer a barrier to seepage.

1.5.5 Model Components for the Human Intrusion Scenario

The TSPA-LA Model considers a stylized Human Intrusion Scenario based on a simulated future exploratory drilling operation that penetrates the repository. The scenario considers a drilling operation that utilizes the most sophisticated drilling apparatus currently available. Using current technology, if the drilling apparatus encountered a WP, it would easily be detected by a driller because of the combination of the WP or DS resistance to penetration and the presence of metal in the drilling cuttings. Encountering DSs or WPs would not only alert the driller to the presence of non-natural materials, but the strength of the DSs and WPs would be enough to prevent the penetration of the WP by the drilling apparatus. However, if the drilling apparatus were to directly intersect a degraded WP, and the borehole were deepened to the SZ, then the borehole could become an avenue for aqueous waste transport. The stylized scenario in NRC Proposed Rule 10 CFR 63.322 [DIRS 180319] supposes that waste from the penetrated WP is transported to the SZ and available to the RMEI. Because only a degraded WP would be penetrated, the TSPA-LA Model for the Human Intrusion Scenario would include simulation of nominal processes until the time of the WP penetration. However, following the penetration, only the waste transported down the borehole would be evaluated for dose to the RMEI, and the waste transport would be simulated by only the SZ and biosphere model components. Therefore, the Human Intrusion Scenario Modeling Case would involve the following TSPA-LA Model components:

- UZ Flow
- EBS Environment
- WP and DS Degradation
- Waste Form Degradation and Mobilization
- SZ Flow and Transport
- Biosphere.

1.6 CONCEPTUAL DESCRIPTION OF PROCESSES RELEVANT TO AN EVALUATION OF POSTCLOSURE PERFORMANCE IN THE ABSENCE OF DISRUPTIVE EVENTS

The following sections describe processes relevant to the evaluation of repository system performance. Information relevant to the technical basis for this conceptual description can be found in *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734], Sections 6, 7, and 8).

Because the repository horizon will be approximately greater than 200 m beneath the land surface (SNL 2007 [DIRS 179466], Table 4-1, Parameter Number 01-06) and the waste forms are solids (with minor gaseous constituents), the primary means for the mobile radioactive constituents of the waste forms to reach the biosphere, in the absence of an unlikely volcanic eruption, will be along groundwater pathways. The waste forms will pose minimal risks to humans, unless all of the following processes were to occur:

- The WPs are breached.
- The waste forms are exposed to water.
- Radionuclides within the waste forms are dissolved in the water.
- Dissolved or colloid-associated radionuclides are released from the repository and transported with the water in the SZ.
- Radionuclide-containing water is discharged, either naturally or at a pumping well, from the SZ.
- Humans or any part of the food chain uses water containing the released radionuclides.

The following sections describe how these processes might occur and how the major components and processes of the Yucca Mountain Repository system could act to affect long-term waste isolation. The discussion is divided into five topics:

- Water movement in the unsaturated tuffs above the repository in the upper natural barrier
- Water and water vapor movement around the repository drifts
- Water movement and radionuclide transport within and through the EBS
- Water movement and radionuclide transport through the unsaturated tuffs, below the repository
- Water movement and radionuclide transport through the SZ aquifers and biosphere.

1.6.1 Water Movement in the Unsaturated Tuffs above the Repository

The following concepts are excerpted from *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6.1.4). Figure 1-12 illustrates the key concepts associated with water movement in the UZ at Yucca Mountain. The source of water in the UZ at the repository horizon is precipitation at the land surface. Climate will control the range of precipitation and land surface temperature conditions. Four potential climate periods, present-day, monsoon, glacial-transition, and a post-10,000-year climate, were identified as being likely from repository closure to the period of geologic stability (Figure 1-13). The present-day climate state is equivalent to the current climate in the Yucca Mountain area as determined from regional meteorological stations. The monsoon climate state is characterized by hot summers, with increased summer rainfall relative to the present-day climate. The glacial-transition climate state has cooler and wetter summers and winters, relative to the present-day climate state. Climate forecasting indicates that, during the next 10,000 years at Yucca Mountain following repository closure, the present-day interglacial climate may persist for 400 to 600 years, followed by a warmer and wetter monsoon climate for 900 to 1,400 years, followed by a cooler and wetter glacial-transition climate for the remaining 8,000 to 8,700 years (BSC 2004 [DIRS 170002], Section 6.6 and Table 6-1). Per the NRC Proposed Rule 10 CFR 63.342(c)(2) [DIRS 178394], the post-10,000-year climate after repository closure until the period of geologic stability will be modeled by sampling a log-uniform probability distribution for deep percolation rates from 13 to 64 mm/year.

A large portion of the precipitation on the Yucca Mountain land surface either runs off into the washes that are cut into the mountain, evaporates from the surface, or transpires from the native plants in the area. The remaining water infiltrates downward through the soil horizon and into the rock. The net amount of total precipitation that infiltrates is called net infiltration. Net infiltration is the source of percolation flux within the UZ, and it provides the water for flow and transport mechanisms that may move radionuclides from the repository to the water table and into the SZ. Net infiltration is spatially and temporally variable because of the nature of the storm events that supply precipitation, and because of the variation in soil cover and topography. Infiltration is believed to be high on side slopes and ridgetops, where bedrock crops out and fracture flow in the bedrock is able to move moisture away from zones of active evapotranspiration.

The net infiltration moves downward through the UZ, driven primarily by gravity. The downward movement of water in the UZ is called percolation. Percolation flux in the unsaturated fractured tuffs occurs in the rock matrix and in the fractures of the rock. Generally, the welded tuff layers have more of the total flux within the fractures because the permeability of the matrix is low, whereas the nonwelded lithologic layers have more of the total flux within the matrix. Water flows through the welded and densely fractured TCw unit mainly through fractures. Within the more porous PTn unit, most of the water flows through the matrix, where the high storage capacity causes a dampening of the infiltration pulses. Small amounts of flowing water preferentially flow along faults that cut through the PTn. Unsaturated flow in the TSw unit occurs primarily through fractures. In addition, some lateral diversion of water occurs as it moves downward from the soil horizon through the UZ. This lateral diversion is caused by the eastward dip of the geologic strata and heterogeneities in the rock because of the different permeabilities of the welded and nonwelded tuffs between land surface and the repository horizon.

1.6.2 Water and Water Vapor Movement around the Repository Drifts

Figure 1-20 illustrates the key concepts anticipated to be associated with water movement around the repository drifts after waste emplacement at Yucca Mountain. Water is one of the principal determining factors of: (1) corrosion of the EBS, (2) waste dissolution, and (3) radionuclide transport from the repository to the accessible environment. The amount and chemical composition of water seeping into waste-emplacement drifts will affect the long-term performance of the repository system.

In the UZ, percolating water encountering a large underground opening will be partly diverted around the cavity. This effect would reduce the amount of liquid water that could enter a waste-emplacement drift or prevent dripping altogether and is due to the formation of a capillary barrier around the cavity. Moreover, during the early stages after closure, the heat from decaying radionuclides will likely vaporize water that approaches the waste-emplacement drifts. The presence of a capillary barrier and a zone of vaporization would limit the amount of water that could potentially contact the WPs.

The heat generated by the decay of radioactive wastes is anticipated to result in elevated rock temperatures in the repository environment for thousands of years after emplacement (SNL 2007 [DIRS 181383], Figure 6.1-1). For the TSPA-LA repository design concept, these temperatures will be high enough, in most locations, to cause boiling conditions in the vicinity of the drifts, thus giving rise to local water redistribution and altered flow paths. Conditions one to several meters above the ceilings of the emplacement drifts could change in several ways that could affect the amount of water seeping into the drifts. Within 50 years after repository closure, the water will first encounter a dry-out zone above the repository drifts. Under boiling conditions, water reaching the dry-out zone would vaporize, thus preventing liquid water from reaching the drifts. Water vapor would tend to move away from the drifts and through the permeable fracture network, driven primarily by a pressure increase caused by boiling. In cooler regions away from the drifts, the vapor would condense in the fractures, where it could drain either toward the heat source from above or shed around the drifts into the zone below the heat source. Condensed water could also imbibe from fractures into the matrix, leading to increased liquid saturation in the rock matrix.

For the TSPA-LA repository design concept, the dry-out zone around drifts may extend from a few to more than 25 m from the walls of the drifts. Boiling conditions in the rock are anticipated to range from no boiling to boiling for over 2,000 years after emplacement (SNL 2007 [DIRS 181383], Section 8.2[a] and Table 6.3-39), reflecting the spatial and temporal variability of possible TH conditions in the repository system. The spatial variability would be caused by heterogeneity in the rock properties and variations in the ambient percolation flux. In addition, differences in the thermal output of different WPs could cause a range of TH conditions in the repository environment. For example, cooler regions are expected along the edges of the repository and near low-thermal output WPs. The temporal variability in water movement around the drifts could be caused, in the short-term, by the thermal output of the wastes that will eventually decline to minimal values. Hundreds of years of drying and several thousand years of cooling and rewetting are anticipated. In the long-term, water movement will be controlled by the climatic variability (BSC 2004 [DIRS 170002], Sections 6.6) and percolation flux at the repository horizon. If water ultimately penetrates the dry-out zone as the repository cools and reaches the immediate vicinity of the walls of the drifts, most of it will still be prevented from seeping into the drift because of the capillary barrier effect.

The characteristics of the rock around the repository openings may change with time. The fracture permeability could increase because of mechanical stress relaxation following the construction of the repository drifts, and ultimately, the drifts could collapse. The fracture permeability may also change because of rock thermal expansion and mineral precipitation. The capillarity of the fractures could either increase or decrease because of these same processes. However, these changes are not expected to significantly affect seepage into emplacement drifts (DTN: MO0706SPAFEPLA.001_R0 [DIRS 181613], FEPs 2.1.08.01.0A, 2.1.08.02.0A, 2.2.01.01.0A, 2.2.01.01.0B, and 2.2.01.03.0A).

In summary, the rate of water dripping into an emplacement drift is expected to be significantly less than the local percolation rate because of the following:

- The dry-out zone around the drifts will reduce liquid water flow while the temperatures in the drifts are elevated, potentially preventing water from reaching the drift surfaces.
- The capillary barrier will divert water around the drifts.

1.6.3 Water Movement and Radionuclide Transport within and through the Engineered Barrier System

Figures 1-21 and 1-17 illustrate the key concepts associated with TH processes, including water movement within the drifts and water contacting the WPs that may experience water dripping from the walls of the emplacement drifts.

The heat output from the SNF and HLW will decline continuously because of radioactive decay. WP heat output will be highest during the nominal 50-year preclosure period, but the emplacement drifts will be ventilated to remove most of the heat (SNL 2007 [DIRS 179466], Table 4-2). Temperatures of the WPs and DSs will be elevated, and some WPs and DSs may approach the boiling point of water immediately after emplacement, depending on ventilation. However, the warming of ventilation air will ensure that preclosure conditions will be relatively dry with low humidity. At permanent closure, ventilation will cease. The temperature of the drift-wall rock will be below boiling initially, but will increase sharply within a few decades (SNL 2007 [DIRS 179466], Table 4-2). The maximum postclosure temperatures of a WP and DS at any location will be determined by the history of heat output from the waste, the resistance to dissipation of heat in the host rock, heat transfer from the WPs to the DSs and to the walls of the drifts, and the relationship to other nearby heat sources.

Vaporized water within the drifts will tend to move away from hotter regions within the drifts and will condense at cooler locations on the walls of the drifts or in the adjacent rock. Some of this condensed water could then drip directly onto an underlying DS or move along the walls of the drifts to the invert.

Evaporation of dripping water could result in the evolution of highly saline brines on the surfaces of the DSs. The dominant degradation mode of the titanium DSs may be by general corrosion. Because this process is anticipated to be very slow, DS failure is not expected to occur during the 10,000-year period after repository closure. Therefore, the integrity of the DSs could reduce any damage to WPs in the event of rockfall as the emplacement drifts degrade over time.

Significant degradation of the WPs is not expected during the preclosure period. In the postclosure dry-out regime, when drift-wall temperatures are greater than the boiling point of seepage water, potentially relevant high-temperature modes of degradation include SCC and localized corrosion, and dry oxidation is conservatively accounted for by applying aqueous general corrosion rates. In the transition regime, the temperatures of the walls of the drifts are estimated to be approximately equal to the boiling point of the seepage water, and evaporation could cause seepage waters to become concentrated on the surfaces of the WPs if the DSs were to fail. These concentrated brines could result in localized corrosion of the WPs. In lower temperature regions, seepage waters could enter the drifts, but the thermal driving force for localized corrosion would be less and general corrosion, SCC, and MIC may lead to WP failure.

The temperatures of the surfaces of the WPs, the chemistry of the water in contact with the surfaces of the WPs, the mechanical stress, and the degradation characteristics of the metals themselves will affect the degradation rates of Alloy 22 and stainless steel (no credit is taken for the stainless-steel portions of the WPs relative to the corrosion failure of the WPs). Because these environmental parameters are spatially variable, and because the metal fabrication could be variable, WP degradation is also expected to be variable in space and time. Although degradation will occur, WPs are not anticipated to be breached during the first 10,000 years after repository closure. The only exceptions may be a small number of potential early WP failures because of manufacturing defects.

Until a WP has been sufficiently degraded to allow an opening to form through its two metallic liners, there is no potential for water to come into contact with the waste forms. During this period, the waste forms are completely contained within the WPs. If there is a breach of a WP, some of the water vapor or dripping water could enter a WP. When cracks develop in WPs, available water may enter WPs by diffusion through the cracks. However, if there are larger WP failures such as patches, and if there is DS failure that allows water to fall directly on the WPs and the patches, then water may enter the WPs by advection.

Figure 1-17 illustrates the key concepts associated with water moving into the WPs and contacting the waste forms. Figure 1-17 also illustrates the transport of radionuclides through the EBS. These radionuclides may be mobilized as either dissolved species or they may be adsorbed onto colloids.

Water may enter breached CSNF WPs and contact the waste forms, which are assumed to have failed cladding. CDSP WPs will contain HLW glass placed in stainless-steel pour canisters and DSNF fuel assemblies in stainless-steel canisters. Because DSNF cladding may or may not be fully intact, DSNF is modeled as not having any cladding.

The rate at which radionuclides may be released from the repository will depend on the following:

- Degradation rates of the components of the EBS
- Dissolution rate of the waste forms
- The form of the released radionuclides (colloidal versus dissolved)
- Sorption of radionuclides onto corrosion products and invert material
- The solubility of the radionuclides
- The rate of water movement and volume of water that flows or diffuses through the EBS.

1.6.4 Water Movement and Radionuclide Transport through the Unsaturated Tuffs below the Repository

Figure 1-18 illustrates the key concepts associated with water movement in the unsaturated rocks beneath the repository and the migration and transport of radionuclides in these rocks. After the dissolved or colloidally attached radionuclides are released into the UZ beneath the repository, they may be transported with the water to the SZ.

Radionuclide transport within the UZ is strongly related to UZ flow through advective transport. Advective transport (advection) refers to the movement of dissolved or colloidal materials because of the bulk flow of fluid. In the welded units, advection through fractures is expected to dominate transport, mainly because liquid water largely flows through fracture networks in these units. Advection is also an important mechanism for transport between fractures and matrix, especially at interfaces between nonwelded and welded units where there is a transition between dominant matrix flow and dominant fracture flow, respectively.

Liquid water flow paths below the repository horizon will affect advective transport of released radionuclides, particularly in perched water bodies, where lateral transport of radionuclides is likely to occur. Dominant fault-and-fracture flow provides relatively short transport times for transport to the water table, whereas dominant matrix flow leads to much longer transport times. In addition to advection, radionuclide transport within the UZ will be affected by several other mechanisms, such as matrix diffusion, sorption, colloid-facilitated transport, and radioactive decay. Matrix diffusion refers to solute transport from fracture networks to surrounding matrix blocks resulting from molecular diffusion. Mass transfer between fractures and matrix may play an important role in transport within Yucca Mountain. Because flow velocity in the matrix is much slower than in fractures, the transfer of radionuclides from fractures to the matrix by matrix diffusion could retard the overall transport of radionuclides to the water table.

The transport of radionuclides may also be affected by sorption and colloid attachment. Sorption describes a combination of chemical interactions between dissolved radionuclides and the solid phases (immobile rock matrix or colloids), including adsorption, ion exchange, surface complexation, and chemical precipitation. Radionuclide transport in the UZ also involves a colloid-facilitated transport mechanism. Colloids are particles small enough to become suspended (and thus transportable) in a liquid. Radionuclides can be sorbed onto colloids. Unlike the sorption of radionuclides to the rock matrix, however, the radionuclides sorbed on colloids are potentially mobile.

Radioactive decay can also affect the concentration of radionuclides during transport through the UZ. For simple decay, radionuclide concentration decreases exponentially with time, thereby creating stable decay products. Chain decay adds additional complexity because of the ingrowth of new radionuclides created from the decay of a parent radionuclide. Daughter products from chain decay may have different sorption characteristics than their parent radionuclides, therefore exhibiting different modes of transport.

Because each of the characteristics of the natural environment and the processes controlling transport are variable in space and time, radionuclide transport is also variable. Part of the temporal variability relates to long-term climatic changes that not only affect the percolation flux through the repository system but could also cause the water table beneath Yucca Mountain to rise during wetter climates or fall during drier climates. A rise in water table elevation would be accompanied by a potentially increased flow through the repository in response to a wetter climate. Also, a higher water table could shorten transport times through the UZ below the repository, depending on the height of the water level rise.

1.6.5 Water Movement and Radionuclide Transport through the Saturated Zone Aquifers to the Biosphere

Radionuclides that are transported through the UZ below the emplacement drifts are released to the SZ beneath the repository. Figure 1-22 illustrates the key concepts associated with water movement and the transport of radionuclides in the SZ beneath and downgradient from the Yucca Mountain site. Figure 1-22 also illustrates the pathways by which dissolved radionuclides and colloids may come into contact with the biosphere.

When radionuclides released from the repository reach the SZ, they will be transported laterally within the SZ. The general direction of groundwater flow in the SZ is to the southeast, and then to the south and southwest. The processes that affect the performance of the SZ barrier include both groundwater flow and radionuclide transport processes. The groundwater flow processes determine the rate of water movement within the SZ and the flow paths. Dissolved radionuclides diffuse from fractures in which they are advectively transported into the matrix, which has little advective flux and tends to slow the transport time of these species. The effectiveness of this process depends on the diffusive properties of the matrix and the degree of spacing between the flowing fracture zones. Larger diffusion coefficients or smaller spacing between flowing fracture zones result in slower transport times within the fractured rock.

Many radionuclides that are potentially important to repository performance may be sorbed within the matrix of the rock mass. The degree of sorption depends on the individual radionuclide. Carbon, technetium, and iodine are not sorbed (SNL 2008 [DIRS 183750], Sections 6.5.3.1 and 6.7.1) and are transported considering only advection, dispersion, and matrix diffusion processes. Other radionuclides, such as neptunium, uranium, and plutonium, are sorbed in the matrix of the fractured tuffs and alluvium (SNL 2008 [DIRS 183750], Section 6.7.1). The stronger the sorption, the longer the radionuclide transport time compared with advective-dispersive transport times. However, radionuclide transport could be enhanced by colloid-facilitated transport when radionuclides are sorbed onto mobile colloids whose size allows transport along fractures.

The TSPA-LA Model calculates the time for radionuclides to reach the boundary of the controlled area (10 CFR 63.302 [DIRS 180319]) downgradient from the repository. The time required depends primarily on the groundwater velocity and the retardation of radionuclides that may sorb on the mineral surfaces within the volcanic or alluvial aquifers. A rise in the water table elevation could cause a change in the locations of downgradient discharge points and possibly alter transport times if formations of differing transmissivity are encountered by the higher water table.

If radionuclides were to reach a location downgradient from the repository where water is being pumped from the aquifer, the potential exists for radionuclides to come into contact with humans through biosphere pathways. The TSPA-LA Model calculates dose to the RMEI based on an annual water demand of 3,000 acre-feet. In addition, the biosphere submodel includes the potential effect of a rise or fall in water table elevation because the TSPA-LA Model calculates biosphere dose conversion factors (BDCFs) based on a unit concentration in water, regardless of origin.

The principal biosphere pathways to humans consist of the following in approximate order of importance:

- Direct consumption of water containing dissolved radionuclides
- Inhalation of dust that may contain attached radionuclides
- Inhalation of aerosols from evaporative coolers
- Raising fish in contaminated water and subsequent consumption of the fish
- Watering of livestock with contaminated water or feeding of livestock with contaminated crops, or both, and the subsequent consumption of meat, milk, or eggs
- Consumption of crops produced using water containing dissolved radionuclides
- Direct exposure to contaminated soil.

1.7 CONCEPTUAL DESCRIPTION OF PROCESSES RELEVANT TO AN EVALUATION OF POSTCLOSURE PERFORMANCE AFTER THE OCCURRENCE OF DISRUPTIVE EVENTS

Section 1.6 describes processes relevant to repository performance in response to nominal conditions. The following sections describe processes relevant to the evaluation of repository system performance likely to occur in response to natural disruptive events that may affect the repository system. Natural disruptive events that may affect the repository include an igneous intrusion intersecting the repository, a volcanic eruption from a volcanic conduit that intersects repository drifts, and seismic activity that produces vibratory ground motion and/or fault displacement that affects the EBS.

As described in Section 1.6, the primary means for radionuclide transport to the biosphere, in the absence of an unlikely volcanic eruption, will be along groundwater pathways. If disruptive events occur and if these events affect the EBS, the disrupted parts of the EBS will transport radionuclides through the UZ using the nominal processes described in Section 6.3. The following sections describe how these processes might differ from those described in Section 1.6 because of disruptive events.

1.7.1 Water Movement in the Unsaturated Tuffs above the Repository

Figure 1-12 illustrates the key concepts associated with water movement in the UZ at Yucca Mountain. Disruptive events are not expected to affect precipitation at the land surface, which is the source of water in the UZ at the repository horizon (SNL 2007 [DIRS 184614], Section 6.1.4). Likewise, flow fields in the UZ above the repository will not be affected by disruptive events. The climate states incorporated in the TSPA-LA Model are the same for all modeling cases and scenario classes (Section 1.6.1).

1.7.2 Water Movement around the Repository Drifts

As described in Section 1.6.2, in the absence of disruptive events, the rate and chemical composition of seepage into the repository's emplacement drifts is expected to be substantially less than the local percolation rate because of the early-time dry-out zone around the drifts that will reduce liquid water flow while the temperatures in the drifts are elevated, and the strength of the capillary barrier around the drifts. In addition, changes in mechanical stress coupled with the mechanical properties of the rock surrounding the repository will eventually cause drifts to collapse and alter the quantity and location of seepage.

The Igneous Intrusion Modeling Case considers the case where magma that intrudes every drift in the repository emplacement drifts damages all CSNF WPs and CDSP WPs in the intruded drifts, and solidifies. The waste forms are instantly degraded and radionuclides become available for transport through normal dissolution processes when seepage re-enters the drifts. The radionuclide transport to the UZ is controlled by the amount of seepage and radionuclide solubilities, and the solidified magma has hydrologic characteristics similar to the local bedrock.

The Seismic Scenario Class modeling cases include disruptive events in which there are expected changes in the UZ above the repository that will affect the factors controlling seepage into the drifts. The principal changes to these modeling cases are expected to be in the distribution and quantity of seepage as described in *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6.7). Seepage into the repository depends on the integrity of the drifts, the surface area of the drifts, the value of capillary strength, and whether or not a drift lies in the lithophysal or non-lithophysal zone. The more degraded a drift becomes, the more seepage enters the repository. Seismic disruptive events will degrade the repository drifts by causing a loss of integrity of the walls and ceiling of the emplacement drifts. In general, the greater that loss of integrity, the greater the seepage. The most extreme variance in seepage into the repository drifts is expected to occur when a seismic event triggers complete collapse of the repository drifts in the lithophysal zone, increasing the seepage to the value of the percolation flux with no assumed physical retardation of seepage. Collapse of the non-lithophysal areas of the drifts will also increase seepage but not to the value expected for the lithophysal zones.

1.7.3 Water Movement and Radionuclide Transport within and through the Engineered Barrier System

Section 1.6.3 illustrates and describes the TH processes related to the movement of seepage water within the drifts and seepage contacting WPs under the influence of nominal processes. The disruptive events expected to have the most influence on aqueous geochemical processes in the repository environment are seismic events and a possible igneous intrusion that enters the repository drifts. There are two modeling cases that analyze responses to seismic events and one modeling case that is concerned with an igneous intrusion into the repository.

Section 1.7.2 briefly describes the disruption of the pattern of seepage into the repository that can occur in response to seismic events. In addition, rock and seepage responses to seismic events can affect fluid flow within the EBS after seismic activity. Enhanced seepage into the repository, coupled with disruption of the EBS, WP and DS degradation, and waste-form degradation processes in the EBS as described in Section 1.6.3. Further, water flow in rubble in the repository in response to seismically influenced rockfall would encounter little resistance because of the relatively high porosity and permeability of the rubble. However, the repository invert is not expected to be as disrupted under the seismic modeling cases. Therefore, although there could be enhanced degradation and release of waste from the EBS following seismic ground motion or fault displacement, transport of waste following liberation from the WPs would follow nominal processes through the invert.

The rate at which radionuclides may be released from the repository due to seismic activity will depend on the following:

- The number and extent of WP damage
- Dissolution rate of the waste forms in the failed WPs
- Whether or not the released radionuclides are dissolved or colloidally attached
- Whether or not the released radionuclides are sorbed onto corrosion products and invert material
- The solubility of the released radionuclides.

The Igneous Intrusion Modeling Case simulates the number of WPs damaged and failed when portions of the repository are affected by magma that reaches the repository environment through a dike that breaches the repository as described in *Number of Waste Packages Hit by Igneous Events* (SNL 2007 [DIRS 177432], Section 7.1). This modeling case assumes that for any drift intersected by a dike, all WPs in the drift will be failed by contact with magma. All waste from the failed WPs will be incorporated in the cooled magma or otherwise available for transport out of the repository subject to nominal processes.

The rate at which radionuclides released from the failed WPs may be released from the repository will depend on the following:

- Whether or not and at what rate the radionuclides released from the failed WPs are available to be dissolved
- Whether or not the released radionuclides are dissolved or colloidally attached
- Whether or not and at what rate the radionuclides released from the failed WPs are available for sorption onto corrosion products and invert material
- The solubility of the released radionuclides
- The rate of water movement and volume of water that flows or diffuses through the cooled magma and/or the damaged EBS.

1.7.4 Water Movement and Radionuclide Transport through the Unsaturated Tuffs below the Repository

Section 1.6.3 illustrates and describes the processes related to the movement of water and transport of radionuclides released from the repository under the influence of nominal processes. The principal difference between the nominal scenarios and scenarios that include disruptive events is the impetus for the release of radionuclides from the WPs and waste forms. Section 1.7.3 describes the factors relevant to the mobilization of radionuclides as a result of disruptive events. After disruptive events have mobilized radionuclides as a result of igneous or seismic events, radionuclide transport of dissolved or colloidal materials within and through the UZ will be governed by the same nominal processes described in Section 1.6.4.

1.7.5 Water Movement and Radionuclide Transport through the Saturated Zone Aquifers to the Biosphere

Section 1.6.3 illustrates and describes the processes related to the movement of water and transport of radionuclides released from the repository under the influence of nominal processes. Section 1.7.3 describes the factors relevant to the mobilization of radionuclides after disruptive events. Section 1.7.4 describes radionuclide transport of dissolved or colloidal materials by nominal processes within and through the UZ after release from the EBS by disruptive events. In a similar way, radionuclide transport of dissolved and colloidal materials through the SZ to the biosphere will be governed by the same nominal processes described in Section 1.6.5. The TSPA-LA Model treats SZ flow and transport in the same way for both the Nominal Modeling Case and modeling cases that include disruptive events. In addition, the TSPA-LA Model uses the nominal BDCFs for the both the Igneous Intrusion Modeling Case and the Seismic Scenario Class modeling cases.

1.7.6 Atmospheric Transport and Redeposition of Radionuclides

The TSPA-LA Volcanic Eruption Modeling Case simulates the fate and transport of radionuclides deposited on the land surface and dispersed into the atmosphere as a result of a volcanic eruption that intersects the repository. The Volcanic Eruption Modeling Case is described in Section 6.5.2. This modeling case considers waste from WPs that fail when a volcanic conduit intersects the repository environment as described in *Number of Waste Packages Hit by Igneous Events* (SNL 2007 [DIRS 177432], Section 7.2). The Volcanic Eruption Modeling Case considers the WPs that are intersected by a volcanic conduit to be fragmented and directly released by a volcanic eruption at land surface and that a portion of that waste will be incorporated with tephra erupted into the atmosphere. The atmospheric transport and dispersal of tephra and waste particles in the eruptive cloud released during the volcanic eruption is described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 177431]). The dispersal and deposition is simulated using ASHPLUME (ASHPLUME_DLL_LA V. 2.1, STN: 11117-2.1-01 [DIRS 180147]). The ASHPLUME conceptual model accounts for incorporation and entrainment of waste fuel particles associated with a hypothetical volcanic eruption through the repository and downwind transport and deposition of contaminated tephra. ASHPLUME describes the conceptual model in mathematical terms to predict radioactive waste/ash deposition on land surface.

The contaminated tephra on the land surface is then subject to redistribution and dilution by hillslope and fluvial processes. The conceptual and mathematical model of redistribution processes implemented by the TSPA-LA Model is described in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 179347]). The tephra redistribution conceptual model is implemented with FAR V. 1.2 (STN: 11190-1.2-00 [DIRS 182225]). Three major processes are considered by the tephra redistribution conceptual model to predict waste concentration at the RMEI location for the Volcanic Eruption Modeling Case: (1) mobilization from hillslopes, (2) mixing and dilution with uncontaminated sediments during channel transport, and (3) diffusion into the soil column at the RMEI location.

The waste inventory in the CSNF and CDSP WPs hit by the erupting magma provides the radionuclides in the waste-contaminated tephra. Radionuclide concentrations in the waste-contaminated tephra are proportional to those in the waste inventory, subject to radionuclide decay. The biosphere component of the Volcanic Eruption Modeling Case contains appropriate BDCFs to calculate the annual dose associated with predicted radionuclide concentrations at the RMEI location due to three exposure pathways: (1) short-term inhalation exposure, (2) long-term inhalation exposure, and (3) ingestion and radon exposure. The Biosphere Model Component of the Volcanic Eruption Modeling Case is described in Section 6.3.11.

The TSPA-LA Volcanic Eruption Modeling Case considers only the post-eruption situation where volcanic tephra has already been deposited on the ground surface. The Volcanic Eruption Modeling Case does not include evaluation of the annual dose received during the volcanic eruption phase when the ash is transported and dispersed in the atmosphere. Section 6.4.2.5 presents an analysis showing that the mean annual dose during the eruption phase is much lower than the mean annual dose after the eruption.

1.8 CONSERVATISMS AND LIMITATIONS RELATED TO THE TSPA-LA MODEL

1.8.1 Conservatisms Incorporated in the TSPA-LA Model

The submodels incorporated into the TSPA-LA Model are representations of the repository system. The guiding principles during the development of these submodels were to: (1) ensure that representations were not optimistic (i.e., leading to an underestimation of the dose results), and (2) incorporate all included FEPs. Although these representations were developed to be as realistic as possible, some conservative (reasonable and technically defensible based on supporting analyses) representations were required for complete development of the TSPA-LA Model. These conservatisms and models are appropriate and within the regulatory guidelines for the TSPA-LA effort, as found in NRC Proposed Rule 10 CFR Part 63 ([DIRS 178394] and [DIRS 180319]). Conservatisms incorporated in the TSPA-LA Model, if present, are not functions of the TSPA process, but are a result of the approach, methodology, and assumptions used in the abstractions found in the supporting analyses and process models described therein.

The NRC Proposed Rule 10 CFR 63.114(a)(2) [DIRS 178394] requires that a PA:

> "Account for uncertainties and variabilities in parameter values, for 10,000 years after disposal, and provide for the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment."

Also, NRC Proposed Rule 10 CFR 63.304 [DIRS 180319] requires that the ranges of parameters and performance-assessment calculations provide a Reasonable Expectation of repository performance in the following way:

> *"Reasonable expectation* means that the Commission is satisfied that compliance will be achieved based upon the full record before it. Characteristics of reasonable expectation include that it:

1. Requires less than absolute proof because absolute proof is impossible to attain for disposal due to the uncertainty of projecting long-term performance;
2. Accounts for the inherently greater uncertainties in making long-term projections of the performance of the Yucca Mountain disposal system;
3. Does not exclude important parameters from assessments and analyses simply because they are difficult to precisely quantify to a high degree of confidence; and
4. Focuses performance assessments and analyses on the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values."

Accordingly, because 10 CFR 63.304(4) [DIRS 180319] does not preclude the use of conservative parameter values, the approach used for the TSPA-LA Model was to use full ranges of 'reasonable and defensible' distributions of estimates of parameter values that also could include conservative estimates of their values as provided by the supporting analyses. The TSPA-LA Model approach integrates the abstraction models developed in the supporting analyses to describe the relevant FEPs and appropriately propagate uncertainty in these abstractions. The TSPA-LA Model embodies all the assumptions, limitations, differences, and conservatisms of the underlying abstractions, process models, and related analyses.

The intended purpose of the TSPA-LA Model (SNL 2008 [DIRS 184920], Section 1.1.1) is to provide a defensible basis for an evaluation for compliance with the adopted postclosure regulatory standards (e.g., NRC Proposed Rule 10 CFR Part 63 [DIRS 178394] and [DIRS 180319]). Defensibility includes, but is not limited to, reasonable and technically defensible conservative estimates of expected dose or other performance measures. The development of the TSPA-LA Model employed the following measures in providing defensible estimates of repository performance:

- Providing the best available estimates of parameter values while covering their ranges of uncertainty, including conservative estimates, where appropriate.
- Documenting the full range of uncertainty and sensitivity analyses and other supporting analyses conducted to evaluate the significance of alternative assumptions to provide confidence in the overall results.
- Providing probabilistic estimates of mean dose, including conservative approaches only where knowledge of a process is limited.

The TSPA-LA Model includes an assemblage of the best available estimates of the parameters and parameter values, including, only when necessary, conservative estimates of parameter values and conservative assumptions related to the underlying process models and submodels. The TSPA-LA Model then uses this information to calculate the best available estimate of repository performance. The descriptions of the TSPA-LA Model components in Section 6.3 include the conservatisms applicable to each of the model components and include, as applicable, conservative values in the ranges of estimates of parameters values.

The preparation for the TSPA-LA Model involved the development of parameter-value distributions to account for uncertainty in parameter values. The TSPA process includes a Parameter Review Team that is responsible for evaluating parameter uncertainty, including the use of conservative parameter values. The Parameter Review Team meets with the authors of each supporting analysis, process model, and submodel that served to develop inputs to the TSPA-LA Model. The Parameter Review Team's goal was to develop realistic parameter-value distributions that appropriately characterize uncertainty. However, in cases where there was insufficient information available to support realistic characterizations, subject matter experts (SMEs) and the Parameter Review Team jointly concurred on conservative treatments of uncertainty. The TSPA-LA Model's parameter distributions are described in Section 4.8 and Appendix M, and further documented in the TSPA Input Database (Section 4.8) and on Parameter Entry Forms (PEFs) (Section 4.4).

1.8.2 Limitations of the TSPA-LA Model

Constraints that influence the TSPA-LA Model relate to the physical system, computer software, computer hardware, input data and knowledge, and limitations of the process models. The physical system is constrained by the given initial conditions, which reflect the complexity of the systems and processes being analyzed. Assessing the performance of a nuclear waste repository, which is sited in the UZ geologic setting at Yucca Mountain, involves numerous coupled physical and chemical processes. The constraints evolve through time, for example, with the gathering of additional scientific data and with advances in computer hardware and software.

The primary limitations on the TSPA-LA Model are described in the following sections. These limitations do not affect the utility of the TSPA-LA Model for achieving its intended purpose of providing a defensible evaluation of repository performance in compliance with applicable regulatory standards.

1.8.2.1 Software Limitations

The TSPA-LA Model uses GoldSim software (GoldSim V. 9.60.100, STN: 10344-9.60-01 [DIRS 181903]). The GoldSim software has the following general capabilities:

- Addresses variability and uncertainty by using Monte Carlo simulation
- Superimposes the occurrence and consequences of discrete events onto continuously varying systems
- Uses model ‘containers’ that facilitate the simulation of large, complex systems
- Dynamically links external process models and/or abstractions directly to the GoldSim software
- Directly exchanges information between any Open Database Connectivity compliant database and the software.

The limitations of the GoldSim software do not affect its ability to achieve its intended purpose of providing a defensible evaluation of repository performance in compliance with applicable regulatory standards.

When developing and integrating the process models that comprise the model components of the TSPA-LA Model, hardware and software limitations were an important consideration in the model abstraction process. Hardware limitations include the speed and number of computer processors available, while software limitations include limits on the size of individual processes and threads in a 32-bit operating system. For Yucca Mountain, the judgment of scientists involved in developing the TSPA-LA Model is that the computational size and efficiency of the underlying process models do not allow direct coupling of most process models. Examples include the process-level TH, thermal-hydrologic-chemical (THC), UZ flow, and biosphere models. Some process models, such as EBS transport, have been built directly into the TSPA-LA Model but most have been abstracted in one form or another, as described in Section 6. The decoupled process models were run separately and converted to abstractions, such as response surfaces and look-up tables, which serve as direct input to the TSPA-LA Model.

1.8.2.2 Computational Limitations

The regulatory requirement to include the effects of model and data uncertainty in the PA of the repository means that the TSPA-LA Model must have the capability of modeling the repository system in a probabilistic fashion, which involves multiple realizations of the future system behavior. Furthermore, there must be a sufficient number of model realizations of the future behavior of the repository system to produce a stable estimate of the mean annual dose. This probabilistic requirement thus places a constraint on the size of the TSPA-LA Model and the run time for individual simulations of repository performance using the hardware configuration described in Section 1.2.5. These software and hardware constraints affected the size of the various pieces during the development of the TSPA-LA Model, including the number of nodes in the three-dimensional UZ flow fields, the number of particles per radionuclide used in the UZ

Transport Model Component, the number of unique radionuclides in all parts of the TSPA-LA Model and software, and also the spatial discretization of the EBS.

For example, the TSPA-LA Model simulates a few strategically defined groups of WPs that share common attributes rather than representing each WP individually. The chemical and thermal conditions for each WP in a group are generally defined by spatial averages or by a single member of the group. For example, the flow rate of seepage is a spatial average across the WPs in a group, and the temperature history is that of a WP selected as representative of the group. This technique reduces the computational requirements on the TSPA-LA Model and still allows simulation of repository performance. In contrast, modeling the full spatial variability in the repository by representing every WP individually in a probabilistic framework would require more computational time than practical with available technology and would provide only minor improvements to the estimates of repository performance.

1.8.2.3 Data Limitations

The TSPA-LA Model utilizes a large amount and variety of field and laboratory data. Source documents for these data, cited in Section 4 and elsewhere in this report, describe the limitations in these data, indicate where additional data could lead to further refinements of the process models and submodels, and provide the bases for the conclusion that the currently available data supporting the TSPA-LA Model are defensible and suitable for their intended use. The limitations on the field and laboratory data used in the TSPA-LA Model do not affect the utility of the model for achieving its intended purpose of providing a defensible evaluation of repository performance in compliance with applicable regulatory standards. In addition, the TSPA-LA Model uses the TSPA-LA Input Database that includes the results of the evaluation of uncertainties in parameter values, and the TSPA-LA Model propagates those uncertainties throughout the analyses.

1.8.2.4 Process Model Limitations

The TSPA-LA Model is a representation of the total repository system, including both natural and engineered components. The model components shown on Figure 1-3 are represented by separate process models, which were based on an analysis of FEPs affecting postclosure repository performance. In most cases, these process models are mathematical representations of physical and chemical processes that will occur in the natural and engineered systems over the life of the repository. The principal investigators who have developed these process models have also developed abstractions, or simplifications, of the process models to be used in the TSPA-LA Model. The abstraction models may be response surfaces, one-dimensional or two-dimensional look-up tables, or software linked to GoldSim as dynamically linked libraries (DLLs). The abstraction models capture the principal features of the process models. Therefore, the TSPA-LA Model is subject to the limitations of the supporting process models. However, although the TSPA-LA Model is subject to the limitations of the process models and submodels contained in supporting analyses, these limitations do not affect the ability of the TSPA-LA Model to achieve its intended purpose of providing a defensible evaluation of repository performance in compliance with applicable regulatory standards. Further, the uncertainty in the TSPA-LA Model is incorporated through the use of distributions of parameter values in Monte Carlo techniques for stochastic model realizations to simulate repository performance.

1.8.2.5 Condition Reports

The *Total System Performance Assessment Model/Analysis for the License Application* addresses the issues raised in the following condition reports (CR):

- *Condition Report-11049* (Use of Unqualified Software)—CR-11049 identifies the in-process TSPA-LA Model's GoldSim outputs, along with the analyses and graphical presentations of those outputs, in the draft TSPA-LA. These model outputs were produced with in-process software that was unqualified at the time and, thus, appear to be noncompliant with current quality assurance procedures. The in-process software has been qualified. During development use of GoldSim is discussed in Section 3.0. Impact analyses will compare the TSPA-LA Model results prepared with the qualified software to the preliminary results prepared using the in-process software. The condition report will evaluate and document whether or not the use of the preliminary in-process software was contrary to procedure and constitutes a condition adverse to quality. The qualified version of GoldSim and its software qualification documentation may be found in Section 3.8, and Table 3-8.

- *Condition Report-11152* (Updates for Draft SEIS-TSPA)—CR-11152 identifies several issues in the TSPA-LA Model relating to the Supplemental Environmental Impact Statement (SEIS). The evaluation and/or resolution of these issues is documented in Appendix P of this TSPA-LA Model/Analysis report.

- *Condition Report-11357* (Pallet Chemical Degradation FEP Status Change)—CR-11357 identifies that FEP 2.1.06.05.0C, 'Chemical Degradation of Emplacement Pallet' has been added to Appendix I of this TSPA-LA Model/Analysis report and the status is listed as included rather than excluded.

- *Condition Report-11382* (OCS Expectations for TSPA)—CR-11382 identifies the following expectations of the Office of Chief Scientist: (1) provide an addendum to the TSPA-LA to address issues identified in the development of the TSPA-LA Model, and (2) address the proposed changes to the regulations governing the preparation of the TSPA-LA Model in this TSPA-LA Model/Analysis report. The planned addendum to this report will document the first issue and will be completed upon approval of this TSPA-LA document. The second issue is documented in Section 1.1.1, Governing Regulations.

- *Condition Report-11424* (Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary Rev03 Typographical Errors)—CR-11424 identifies and tracks the correction of minor typographical errors discovered during the Licensing/Data Qualification review of the TSPA Uncertainty and Sensitivity Analysis. The condition identified in CR-11424 only affects file names and not parameter values. Therefore, the condition has no material effect on TSPA-LA Model calculations.

- *Condition Report-11572* (Issue with Decay Chain Transport in UZ Transport Abstraction Model)—CR-11572 concerns the way in which decay species and decay chains are simulated in fault-zone nodes in the UZ Transport Abstraction. The issue only affects the UZ transport model and a southern release location located on a fault zone. The transport model at these nodes does not include diffusion into the matrix resulting in excessively long transport times to the UZ for decay-chain daughters. The issue affects only 7 percent of the nodes in the model. The issue was resolved by specifying a different southern release location in *Total System Performance Assessment Model/Analysis for the License Application*, as described in Appendix P, Section P21.

- *Condition Report-11581* (Issues Associated with Characterize Eruptive Processes at Yucca Mountain, Nevada Rev03)—CR-11581 concerns a surveillance audit of primary sources for Characterize Eruptive Processes at Yucca Mountain, Nevada. The audit found discrepancies regarding the sources and traceability of primary input data as well as incorrect DIRS referencing. The issues raised in CR-11581 involve record keeping and the quality of the data is not in question. Therefore, CR-11581 is judged to have no material impact on TSPA-LA Model calculations.

- *Condition Report-11584* (Issues Associated with Number of Waste Packages Hit by Igneous Event Rev03)—CR-11584 concerns a surveillance audit of three primary sources for Number of Waste Packages Hit by Igneous Events. The audit found that not all values of the input data could be verified and that some data input values were either not traceable or incorrectly entered into the analysis in Number of Waste Packages Hit by Igneous Events. The documentation issues raised in CR-11584 do not involve the quality of data used in the TSPA-LA Model. Therefore, CR-11584 is judged to have no material impact on TSPA-LA Model calculations.

- *Condition Report-11589* (Issues Associated with Dike/Drift Interactions Rev02)—CR-11589 concerns a surveillance audit of primary sources for *Dike/Drift Interactions.* The audit identified issues associated with the traceability of some data input values, inaccuracies in some data input values, and the Q status of some software used in the analysis in *Dike/Drift Interactions*. Because CR-11589 indicates that the technical information in question is correct, CR-11589 is judged to have no material impact on TSPA-LA Model calculations.

- *Condition Report-11655* (Addenda Planning Documentation)—CR-11655 concerns the issue that the current Technical Work Plan does not address the need for the scope of the addendum that is planned for *Total System Performance Assessment Model/Analysis for the License Application.* In addition, there is no documentation in the records package for the analyses nor is there any documentation in the supplemental records package for the Technical Work Plan.

- *Condition Report-11657* (Addenda Input Inconsistencies)—CR-11657 concerns the issue that although all inputs were listed in the DIRS system report: (1) two references were listed in the DIRS report as direct input but were not included in Section 4 of the Addendum and (2) two references listed in the addendum were identified as established fact current but the DIRS report listed these references as data. The issues raised by CR-11657 involve record keeping only, and data quality is not in question. Therefore, CR-11657 is judged to have no material impact on TSPA-LA Model calculations.

- *Condition Report-11658* (Addenda Records Deficiencies)—CR-11658 concerns three issues: (1) there are two second backcheck copies but only one refers to the SCI-PRO-003 review, (2) there is no concurrence documentation from the Lead or Lead Checker in the records package, and (3) there is no documentation of any deviations to the Technical Work Plan. The issues raised by CR-11658 involve record keeping only, and data quality is not in question. Therefore, CR-11658 is judged to have no material impact on TSPA-LA Model calculations.

1.8.2.6 Other Limitations of the TSPA-LA Model

In addition to the limitations related to software, computational constraints, data, and process models that are discussed in the previous sections, there are the following additional limitations that derive from choices made in the design and implementation of the TSPA-LA Model.

Conservatism—The decision to implement reasonable and technically defensible conservative approaches may cause the TSPA-LA Model to tend to underestimate the overall performance of the repository system or its model components. This limitation does not affect the utility of the TSPA-LA Model for achieving its intended purpose of providing a defensible evaluation of compliance with applicable regulatory standards, because the TSPA-LA Model tends to overestimate, rather than underestimate, radionuclide releases from the repository system and subsequent doses to the RMEI. However, effects of conservative assumptions at the model component level should be considered in interpretations of the realistic behavior of the repository system and its components. Not all conservative assumptions made at the model component level necessarily result in conservative outcomes at the system level: conservatisms that have the potential to increase radionuclide release (or dose) may have little or no impact on overall performance if the model component or process model in which the conservatisms are applied result in only a minor contribution to performance. At any level within the repository system modeled with the TSPA-LA Model, conservative assumptions may tend to mask the relative importance of other processes or parameters, and conclusions regarding the importance, or lack thereof, of aspects of the TSPA-LA Model should be understood as having been made consistent with the conservatisms embedded in the model.

Some abstractions used in the TSPA-LA Model are based on process level models that are limited to conditions under which Darcy's law and its extensions and generalizations are applicable. These abstractions are limited in the TSPA-LA Model to situations in which the differential equations describing fluid flow can be uncoupled from those that describe the mass transport of colloids or dissolved species in the UZ, SZ, and through the EBS, including corrosion products and the invert. The uncoupling is appropriate as long as the density and viscosity of the fluids in the TSPA-LA Model do not change with concentration in such a manner as to significantly alter the flow fields. Density and viscosity values reported for solutions with comparably high concentrations of uranium indicate that the use of Darcy's law and the uncoupling of flow and transport equations under the condition commonly encountered in the TSPA-LA Model are reasonable and appropriate for the model's intended use.

The TSPA-LA Model utilizes some numerical model abstractions from process level models that are limited to conditions under which Fick's first law of diffusion is applicable. This is true for describing diffusive transport in the UZ, SZ, and through the EBS, including the WPs, corrosion products, and the invert. Fick's first law states that mass transport is proportional to the concentration gradient and mass is transported from high to low concentration in such a way as to tend to minimize the gradient. The second and third order effects can contribute to additional diffusive mass transfer under unique situations such as thermal diffusion, pressure diffusion, and external forced diffusion (e.g., under an imposed electrical current). The models invoked in the TSPA-LA either directly or indirectly are limited to situations dominated by ordinary concentration diffusion. Fick's law for mass transport is as fundamental as Fourier's law of heat conduction, which states that the flow of heat by conduction is proportional to the temperature gradient.

Limitations inherent in mathematical modeling and uncertainty analysis—Because the TSPA-LA Model represents complex natural or engineered systems, insights that can be drawn from the model's calculations are limited to those based on processes that have been included in the model. Processes that have been omitted from the TSPA-LA Model, either through the FEP screening process (Section 6.1.3) or through simplifications made as part of the abstraction process (Section 6.3), are not evaluated in detail. This limitation is inherent in mathematical models that simplify complex systems to allow predictive analysis, and does not affect the utility of the model for achieving its intended purpose of providing a defensible evaluation of compliance with applicable regulatory standards. Insights into processes that have been omitted from the TSPA-LA Model or simplified through the abstraction process can be obtained by consulting underlying reports describing analyses that document the FEP screening process and the development of relevant process models, as cited in Section 6.

Similarly, conclusions drawn from sensitivity and uncertainty analyses (Section 9 and Appendix K) are dependent on the design of the TSPA-LA Model and the treatment of uncertainty in its inputs. Because the TSPA-LA Model is based on Monte Carlo uncertainty analysis, the results are sensitive only to those processes and parameters that are included in the model. Sensitivity to uncertainty in parameter values will be directly related to both the roles of the parameters in the mathematical models, and to the distribution of values assigned to the parameters to represent uncertainty. Parameters for which no uncertainty is assigned will not appear as important in the results of standard sensitivity analyses, regardless of their function in the TSPA-LA Model.

1.9 DESCRIPTION OF THE TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL/ANALYSIS FOR THE LICENSE APPLICATION

Total System Performance Assessment Model/Analysis for the License Application describes how the supporting parameters and parameter values, along with process-model abstractions representing many different aspects of the repository system, were integrated into one comprehensive model to describe the total repository system. Modeling activities were conducted and documented in accordance with SCI-PRO-006, *Models*.

Figure 1-23 shows the principal model components of the TSPA-LA Model and the hierarchy of the submodels that support and/or are contained within these model components. References to the documents that describe the development of model components and submodels used to analyze the repository system, and/or provide direct inputs to the TSPA-LA Model, can be found in Table 1-1 and in the list of references in Section 9 of this document. Section 6.1.4 describes the overall approach used to assemble the representations of the individual model components and their submodels into a description of the entire repository system. Descriptions of the model components and submodels used in the TSPA-LA Model, and the scientific bases for these model components and submodels, are presented in Section 6.3.

The TSPA-LA Model documentation consists of four key information sources: (1) *Total System Performance Assessment Model/Analysis for the License Application* (i.e., this report), (2) the numerical model files within the GoldSim model file, (3) the TSPA-LA Input Database, and (4) DTNs submitted to document TSPA-LA Model calculations and analyses. GoldSim allows all linked operations of the abstracted process models and submodels to perform complex calculations, thereby incorporating the natural geochemical and hydrogeologic processes and engineered-design elements of the repository. There are several GoldSim model files developed and documented herein. Appendix B contains DTNs with the results calculated using these various model files. Nominally, the discussion in this document will refer to the GoldSim model file, meaning all related model files.

Total System Performance Assessment Model/Analysis for the License Application describes work performed according to *Technical Work Plan for: Total System Performance Assessment FY 07-08 Activities* (SNL 2008 [DIRS 184920]). Any deviations from the Technical Work Plan (TWP) during the documentation of the TSPA-LA Model, and the subsequent analyses conducted using the TSPA-LA Model, are identified and discussed at the appropriate location. The following exceptions to the TWP also apply:

- Section 7.3 will not contain the entropy analyses described in the TWP.
- Section 7.3 does not explore the sensitivity of parameters with constant values that are chosen from a range of values.
- There were minor immaterial deviations from some desktop protocols referenced in the TWP. These deviations consisted of some changes in naming conventions that did not materially affect the TSPA-LA Model calculations.
- The use of unqualified software for some of the model validation activities described in Section 7.7.2 is documented in corroborative DTNs: MO0708SIMPLIFI.000 [DIRS 182980] and SN0704PMASZFTA.001 [DIRS 182560].
- The Yucca Mountain Acceptance Criteria listed in Table 3.3-1 of the TWP are also discussed in Appendix H.

TSPA-LA Model Analysis Time Period—Two time periods were used for the analysis of repository performance. NRC Proposed Rule 10 CFR 63.311 [DIRS 178394] states the following:

> “(a) DOE must demonstrate, using performance assessment, that there is a reasonable expectation that the reasonably maximally exposed individual receives no more than the following annual dose from releases from the undisturbed Yucca Mountain disposal system:
>
> (1) 0.15 mSv (15 mrem) for 10,000 years following disposal; and

> (2) 3.5 mSv (350 mrem) after 10,000 years, but within the period of geologic stability indicates that performance assessment cover a compliance period of 10,000 years after repository closure."

The TSPA-LA Model analyses presented in Volume III satisfy the 10,000-year requirement of the NRC proposed rule. Some validation analyses in Volume II extend the analysis period to 20,000 years postclosure to allow evaluation of whether or not the trends present at the end of 10,000 years continue, or if uncertainties in results affect the conclusions regarding the 10,000-year performance period and beyond. These extended results do not display any significant changes to the trends observed from 0 to 10,000 years, providing confidence in the conclusions reached regarding the 10,000-year performance period.

The time period for the TSPA-LA Model analyses presented in this document to satisfy the 'period of geologic stability' requirement in 10 CFR 63.311(a) (2) [DIRS 178394] is one million years after repository closure. The one-million-year analyses comply with NRC Proposed Rule 10 CFR 63.302 [DIRS 178394], which indicates that, "This period is defined to end at one million years after disposal." The one-million-year analyses are thus consistent with the proposed NRC Proposed Rule 10 CFR 63.342 [DIRS 178394] and the EPA Proposed Rule 40 CFR 197.25 [DIRS 177357]. The graphical representations of the TSPA-LA Model simulations show the mean annual dose to the REMI observed during the one-million-year postclosure time period.

1.10 DOCUMENT ORGANIZATION

Total System Performance Assessment Model/Analysis for the License Application is organized in three volumes so that the TSPA-LA Model's GoldSim model file and sources of supporting information are fully integrated. The GoldSim model file contains in-depth descriptions of the submodels and descriptions of their implementation. Direct inputs to the TSPA-LA Model are available in the TSPA-LA parameter database, which is the controlled source for the direct inputs to the GoldSim model file. The database allows the user to review most parameter values by accessing a single source location. The information found in Volumes I, II, and III provides cross-referencing that allows investigation of the structure and operation of the TSPA-LA Model's GoldSim files used to perform performance-assessment calculations.

1.10.1 Volume I

Volume I provides a road map to the information required to use the TSPA-LA Model, including detailed information regarding direct inputs, parameters, and submodel descriptions, as required to describe the TSPA-LA Model calculations, and to trace the sources of the TSPA-LA Model's direct inputs. Volume I also contains appropriate references to source information.

Section 1: **Purpose**—Section 1 describes the FEPs process that led to the development of the scenario classes used in analyzing the performance of the repository system. Section 1 also describes the regulatory framework for the TSPA-LA Model as well as an overview of the natural and engineered barriers in the repository system, including site-description information, descriptions of the elements of the EBS, processes affecting water movement through the UZ and SZ, descriptions of the model components, and a general description of the architecture of the TSPA-LA Model.

Section 2: **Quality Assurance**—Section 2 describes the applicable quality assurance (QA) procedures of *Quality Assurance Requirements and Description* (QARD) (DOE 2007 [DIRS 182051]), along with descriptions and references to the methods used for the electronic management of information.

Section 3: **Use of Software**—Section 3 lists and briefly describes the software used in the development of the TSPA-LA Model. The primary software used to run the TSPA-LA Model is GoldSim (V. 9.60.100 [DIRS 181903]). Analysis of the results developed with the TSPA-LA Model is aided by the use of additional postprocessing software. Section 3 identifies and briefly describes all auxiliary software and software routines that were developed for the TSPA-LA Model, including those developed external to, and incorporated into, the TSPA-LA Model.

Section 4: **Inputs**—Section 4 identifies the direct inputs used in the TSPA-LA Model, either by direct tabulations included in this document or through linkage to the appropriate sections of the GoldSim model file or TSPA-LA Model database. Section 4 also identifies all applicable criteria, codes, and standards.

Section 5: **Assumptions**—Section 5 lists the assumptions directly used to perform the TSPA-LA Model analyses along with their bases. Section 5 also includes key assumptions from supporting documents that are used in the TSPA-LA Model.

Section 6: **Model Description**—Section 6 describes the TSPA-LA Model representation of the repository system, presents the scenario classes being analyzed, describes the modeling cases used to analyze the scenario classes, and provides references to the applicable sections of the TSPA-LA Model, the GoldSim model file, and supporting analyses. Section 6 includes detailed descriptions of the conceptual models, mathematical formulations, implementations of the submodels in the TSPA-LA Model, conservatisms, and ACMs.

1.10.2 Volume II

Volume II contains the information supporting the TSPA-LA Model validation.

Section 7: **Validation**—Section 7 describes the validation of the TSPA-LA Model as required by Section 6.3 of SCI-PRO-006, *Models*. Model validation provides confidence that the TSPA-LA Model correctly represents both the natural and engineered systems that constitute the repository. Validation of the TSPA-LA Model involves three stages:

- Validation of the TSPA-LA Model formulation
- Confirmation of the validity of the inputs to the TSPA-LA Model, including verification that the GoldSim software and supporting software codes are correctly implemented and that the inputs are free of errors
- Validation of the simulated repository performance for the postclosure time periods specified in NRC Proposed Rule 10 CFR 63.303 (b) [DIRS 178394].

The model validation of the TSPA-LA Model is consistent with the intended use of the TSPA-LA Model and the required level of confidence. The specific model validation activities documented in Volume II include the following:

- Validation of the interaction of the model components, abstractions, and submodels to ensure that they are working correctly and interfacing properly
- Validation testing the temporal discretization for the TSPA-LA Model scenario classes
- Validation of the statistical stability of the TSPA-LA Model by analyzing the results of a large number of model realizations
- Analysis of the spatial discretization of the TSPA-LA Model, using multiple model realizations to verify that the TSPA-LA Model uses an appropriate number of collection ‘bins’
- Validation of the surrogate waste form used to represent DOE-owned spent fuel
- Corroboration of the results of the abstraction models with validated process models
- Corroboration of the TSPA-LA Model results with natural-analogue information
- A summary of previous technical reviews of the TSPA-LA Model.

1.10.3 Volume III

This volume contains the results of analyses performed with the TSPA-LA Model, inputs and references, and the appendices. These are detailed below.

Section 8: **Analyses**—Section 8 includes conclusions of the analyses as required by SCI-PRO-006. However, the order of presentation and scope of the material presented deviates from the suggestions provided in SCI-PRO-006, Attachment 2. Section 8 contains the results of TSPA-LA Model performance analyses evaluating the postclosure performance of the repository and its compliance with NRC Proposed Rule 10 CFR 63.113 [DIRS 180319] and the performance measures defined in 10 CFR 63.311 (a) (1) and (2) [DIRS 178394]. The probabilistic analyses account for uncertainty and address FEPs that could affect total system performance. Volume III presents the results of analyses and calculations in the following areas:

- System and subsystem performance analyses for the Nominal Scenario Class, including the Nominal Modeling Case; the Early Failure Scenario Class, including the Drip Shield EF and Waste Package EF Modeling Cases; the Igneous Scenario Class, including both Igneous Intrusion and Volcanic Eruption Modeling Cases; and the Seismic Scenario Class, including the GM and FD Modeling Cases
- Groundwater and individual protection analyses consistent with regulatory guidelines in NRC Proposed Rule 10 CFR 63.331 [DIRS 180319] and 10 CFR 63.311 (70 FR 53313 [DIRS 178394]), respectively

- Analysis of the Human Intrusion Scenario
- Analyses of the capabilities and importance of the upper and lower natural barriers and the EBS that have been identified as contributing to repository performance.

Section 9: **Inputs and References**—Section 9 provides the sources of inputs, software, data tracking numbers, and cited references.

Appendices

A. Acronyms and Abbreviations—Appendix A contains a list of acronyms and abbreviations used in this document.

B. Data Tracking Numbers for the TSPA-LA Model—Appendix B describes the contents of the output DTNs for the TSPA-LA Model and the interrelation among the DTNs in the TSPA-LA Model.

C. Performance Margin Analysis—Appendix C describes the PMA, a separate set of TSPA calculations conducted parallel to those of the TSPA-LA Model in order to quantitatively evaluate the model's explicit and implicit conservatisms (Section 6.3). The PMA provides insights into the appropriateness of the TSPA-LA Model's use in satisfying regulatory standards and supports validation of the TSPA-LA Model.

D. Parameter Listing—Appendix D refers to the TSPA Input Database which contains the list of parameters used in the TSPA-LA Model. The database provides a listing of all parameters and identifies the parameter entry form (PEF) that includes each parameter.

E. Response to Review Comments from the International Review Team—An International Review Team (IRT) evaluated the most recent performance assessment of the Yucca Mountain Repository, and provided recommendations for future investigations. Appendix E provides a summary of, and responses to the IRT's recommendations.

F. Dynamically Linked Libraries Description and Feeds—Appendix F provides a brief description of the DLLs used in the TSPA-LA Model, and includes a detailed description of the input files used by the model DLLs.

G. Wiring Diagrams for Model Information Feeds—Appendix G provides a set of color-coded flow charts that illustrate information flow between model components and submodels within the TSPA-LA Model.

H. Yucca Mountain Review Plan Acceptance Criteria—Appendix H evaluates *Total System Performance Assessment Model/Analysis for the License Application* with respect to 10 CFR Part 63, Subpart E (Technical Criteria) ([DIRS 178394 and [DIRS 180319]).

I. Features, Events, and Processes Mapped to TSPA-LA Model—Appendix I provides summary information describing how FEPs relevant to the Yucca Mountain Repository are included and implemented in the TSPA-LA Model. Appendix I also includes descriptions of the screening criteria applied to the identified FEPs and summaries of the screening decisions.

J. Conceptual Structure of TSPA-LA—Appendix J presents a formal description of the conceptual structure of the TSPA-LA Model, including the mathematical description of uncertainty, and derives the equations used to calculate mean annual dose.

K. Uncertainty and Sensitivity Analysis Results—Appendix K presents the distributions of results for each modeling case (uncertainty analyses) and identifies the uncertain parameters that predominantly contribute to the uncertainty in each modeling cases' results (sensitivity analyses).

L. Simplified TSPA—Appendix L describes the 'Simplified TSPA Analysis', a simplified, stand-alone, numerical analysis that corroborates and provides confidence in the results of the TSPA-LA Model.

M. Comparison with Electric Power Research Institute Analysis—Appendix M presents a comparison of the TSPA-LA Model and the TSPA of the Yucca Mountain Repository conducted by the Electric Power Research Institute. The comparison provides an independent means of validation of the TSPA-LA Model.

N. Derivation of Implementing Equations for Waste Package Parsing and Average Damage Area—Appendix N describes the calculations implemented in the TSPA-LA Model that divide the entire set of WPs into smaller groups to mitigate unintended model responses introduced by assigning averaging WP failure properties to WPs with very different properties.

O. Localized Corrosion Initiation Uncertainty Analysis—Appendix O describes the implementation and results of the Localized Corrosion Initiation Uncertainty Analysis, which calculates the chemical conditions on the surfaces of WPs to determine whether or not there are sufficient conditions for the initiation of localized corrosion.

P. Impact Assessments—Appendix P describes post-TSPA-LA Model development activities related to correcting implementation decisions, identification of undocumented conservatisms, and revised parameter values. Appendix P also includes an evaluation of the sensitivity of expected mean annual dose with respect to igneous event frequency, which is not documented elsewhere.

Table 1-1. Principal Documents that Support the TSPA-LA Model

Topic	Title	Document Identifier
UZ Flow		
Climate	*Future Climate Analysis*	ANL-NBS-GS-000008 [DIRS 170002]
Infiltration	*Simulation of Net Infiltration for Present-Day and Potential Future Climates*	MDL-NBS-HS-000023 [DIRS 182145]
Mountain-Scale UZ Flow	*UZ Flow Models and Submodels*	MDL-NBS-HS-000006 [DIRS 184614]
Drift Seepage	*Abstraction of Drift Seepage*	MDL-NBS-HS-000019 [DIRS 181244]
	In-Drift Natural Convection and Condensation	MDL-EBS-MD-000001 [DIRS 181648]
	Seepage Model for PA Including Drift Collapse	MDL-NBS-HS-000002 [DIRS 167652]
EBS Environment		
EBS Thermal-Hydrologic	*Multiscale Thermohydrologic Model*	ANL-EBS-MD-000049 [DIRS 181383]
EBS Chemical Environment	*Engineered Barrier System: Physical and Chemical Environment*	ANL-EBS-MD-000033 [DIRS 177412]
WP and DS Degradation		
WP, General Corrosion, and Localized Corrosion	*General Corrosion and Localized Corrosion of the Drip Shield Barrier*	ANL-EBS-MD-000004 [DIRS 180778]
WP, General Corrosion, and Localized Corrosion	*General Corrosion and Localized Corrosion of Waste Package Outer Barrier*	ANL-EBS-MD-000003 [DIRS 178519]
	Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Material	ANL-EBS-MD-000005 [DIRS 181953]
	Analysis of Mechanisms for Early Waste Package/Drip Shield Failure	ANL-EBS-MD-000076 [DIRS 178765]
Waste Form Degradation and Mobilization		
Radionuclide Inventory	*Initial Radionuclide Inventories*	ANL-WIS-MD-000020 [DIRS 180472]
In-Package Chemistry	*In-Package Chemistry Abstraction*	ANL-EBS-MD-000037 [DIRS 180506]
Cladding Degradation	*Cladding Degradation Summary for LA*	ANL-WIS-MD-000021 [DIRS 180616]
Waste Form Degradation	*CSNF Waste Form Degradation: Summary Abstraction*	ANL-EBS-MD-000015 [DIRS 169987]
	Defense HLW Glass Degradation Model	ANL-EBS-MD-000016 [DIRS 169988]
	DSNF and Other Waste Form Degradation Abstraction	ANL-WIS-MD-000004 [DIRS 172453]
Dissolved Radionuclide Concentration Limits	*Dissolved Concentration Limits of Elements with Radioactive Isotopes*	ANL-WIS-MD-000010 [DIRS 177418]

Table 1-1. Principal Documents that Support the TSPA-LA Model (Continued)

Topic	Title	Document Identifier
Waste Form and EBS Colloids	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	MDL-EBS-PA-000004 [DIRS 177423]
EBS Flow and Transport		
EBS Flow and Transport	*EBS Radionuclide Transport Abstraction*	ANL-WIS-PA-000001 [DIRS 177407]
UZ Transport		
UZ Particle Tracking	*Particle Tracking Model and Abstraction of Transport Processes*	MDL-NBS-HS-000020 [DIRS 184748]
	Calibrated UZ Properties	ANL-NBS-HS-000058 [DIRS 179545]
	Radionuclide Transport Models Under Ambient Conditions	MDL-NBS-HS-000008 [DIRS 177396]
Transport Interface	*Drift-Scale Radionuclide Transport*	MDL-NBS-HS-000016 [DIRS 170040]
SZ Flow and Transport		
SZ Convolute 1-D SZ Transport SZ Flow and Transport	*Saturated Zone Flow and Transport Model Abstraction*	MDL-NBS-HS-000021 [DIRS 183750]
Biosphere		
Biosphere	*Biosphere Model Report*	MDL-MGR-MD-000001 [DIRS 177399]
Disruptive Events		
Seismic Activity	*Seismic Consequence Abstraction*	MDL-WIS-PA-000003 [DIRS 176828]
Igneous Intrusion Modeling Case	*Number of Waste Packages Hit by Igneous Intrusion*	ANL-MGR-GS-000003 [DIRS 177432]
	Dike/Drift Interactions	MDL-MGR-GS-000005 [DIRS 177430]
	Characterize Framework for Igneous Activity at Yucca Mountain, Nevada	ANL-MGR-GS-000001 [DIRS 169989]
Volcanic Eruption Modeling Case	*Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada*	MDL-MGR-GS-000002 [DIRS 177431]
	Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada	MDL-MGR-GS-000006 [DIRS 179347]
	Characterize Framework for Igneous Activity at Yucca Mountain, Nevada	ANL-MGR-GS-000001 [DIRS 169989]

Source: *Technical Work Plan for: Total System Performance Assessment FY 07-08 Activities* (SNL 2008 [DIRS 184920], Table 1-1).

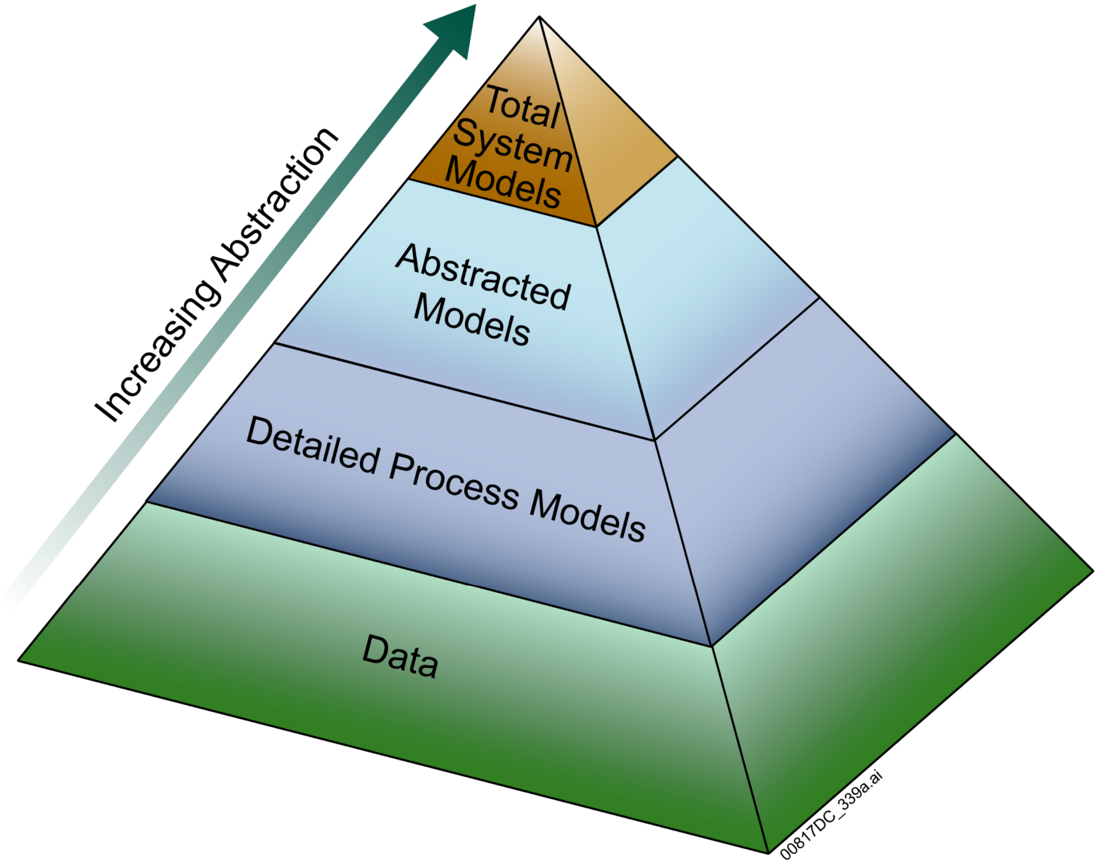


Figure 1-1. Performance Assessment Pyramid Showing the Steps Involved in Developing a Total System Model

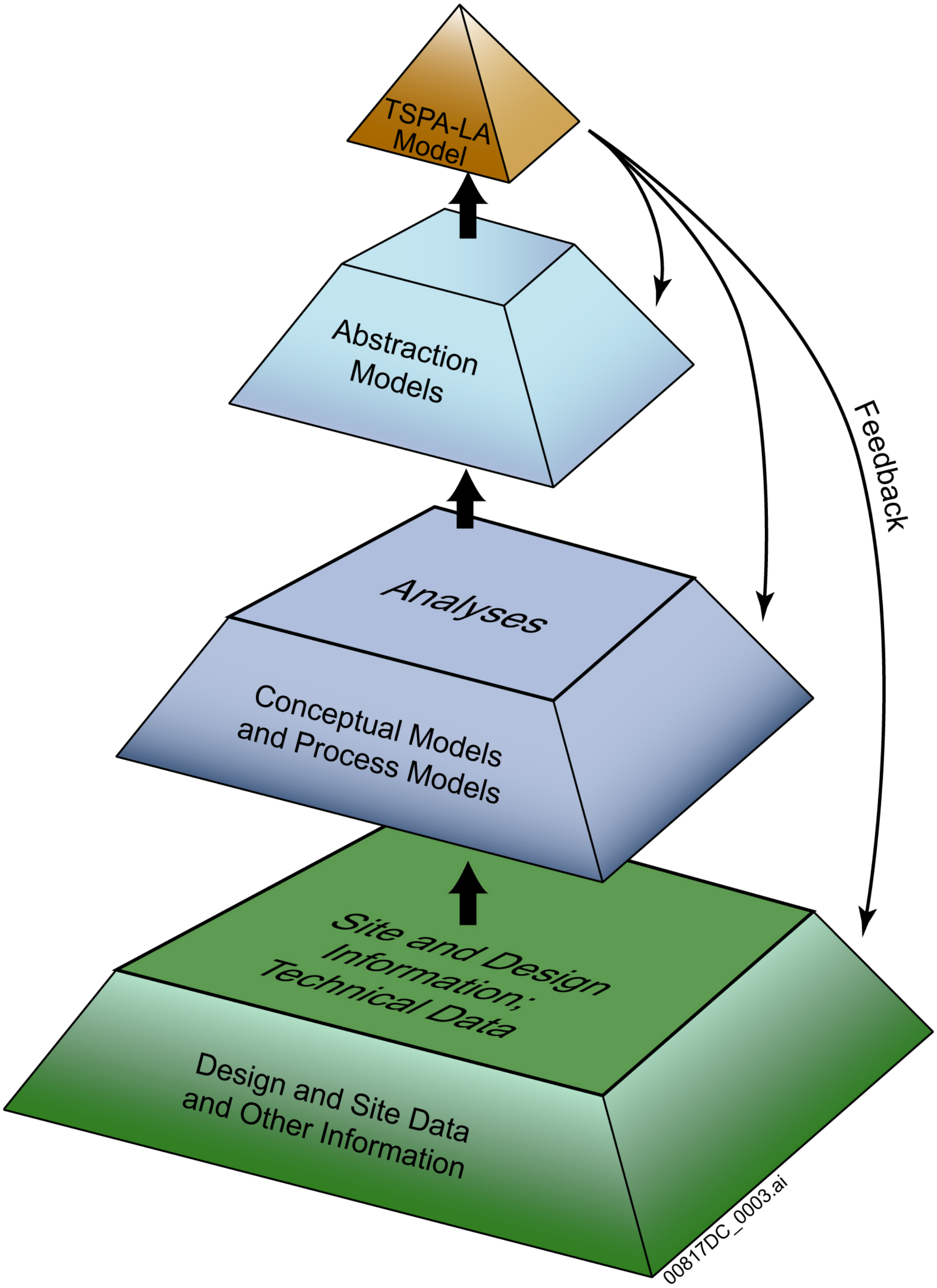


Figure 1-2. Performance Assessment Pyramid Showing How Detailed Underlying Information Builds the Technical Basis for the TSPA-LA Model

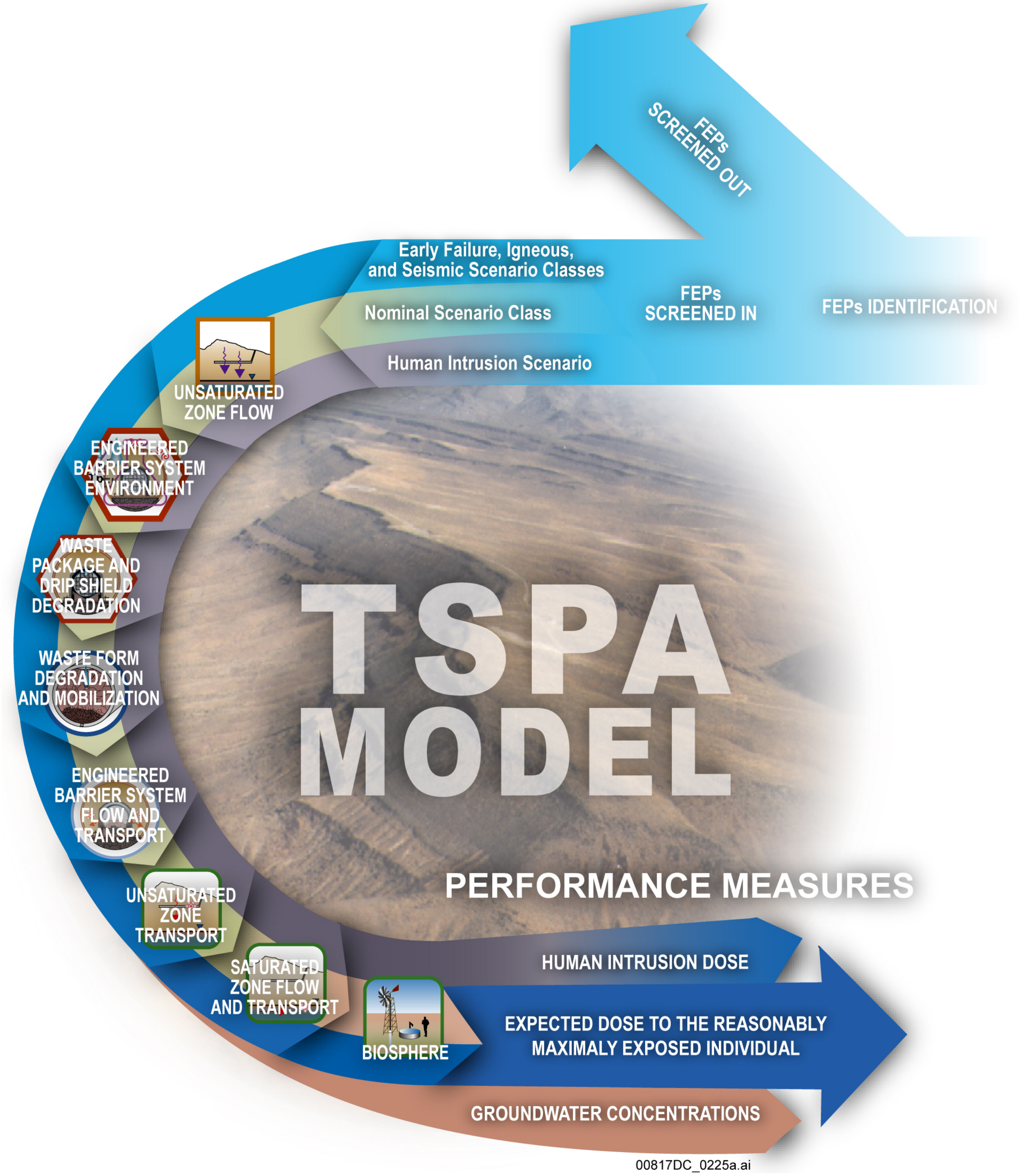
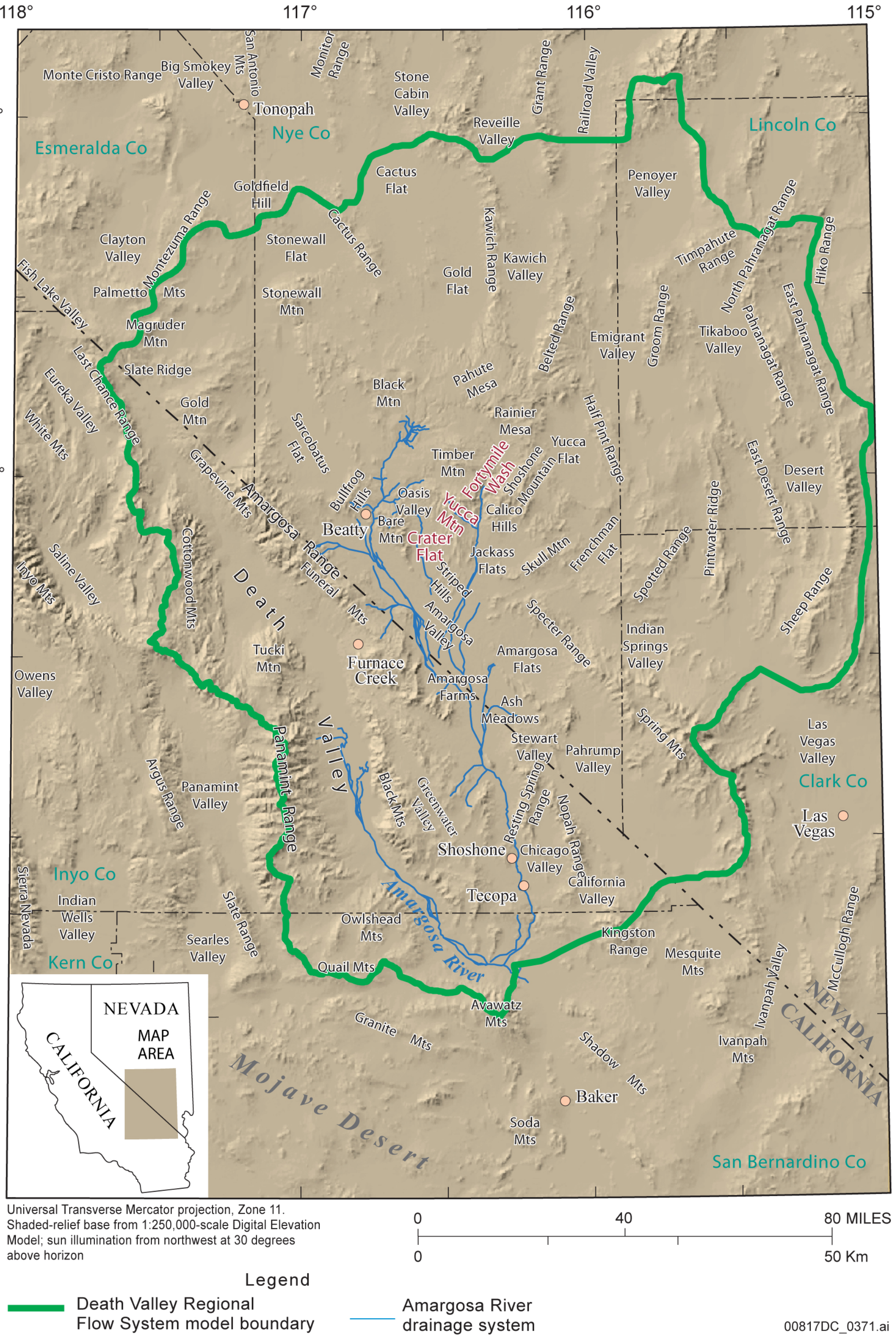


Figure 1-3. Schematic Representation of the Development of the TSPA-LA Model, Including the Nominal, Igneous, and Seismic Scenario Classes



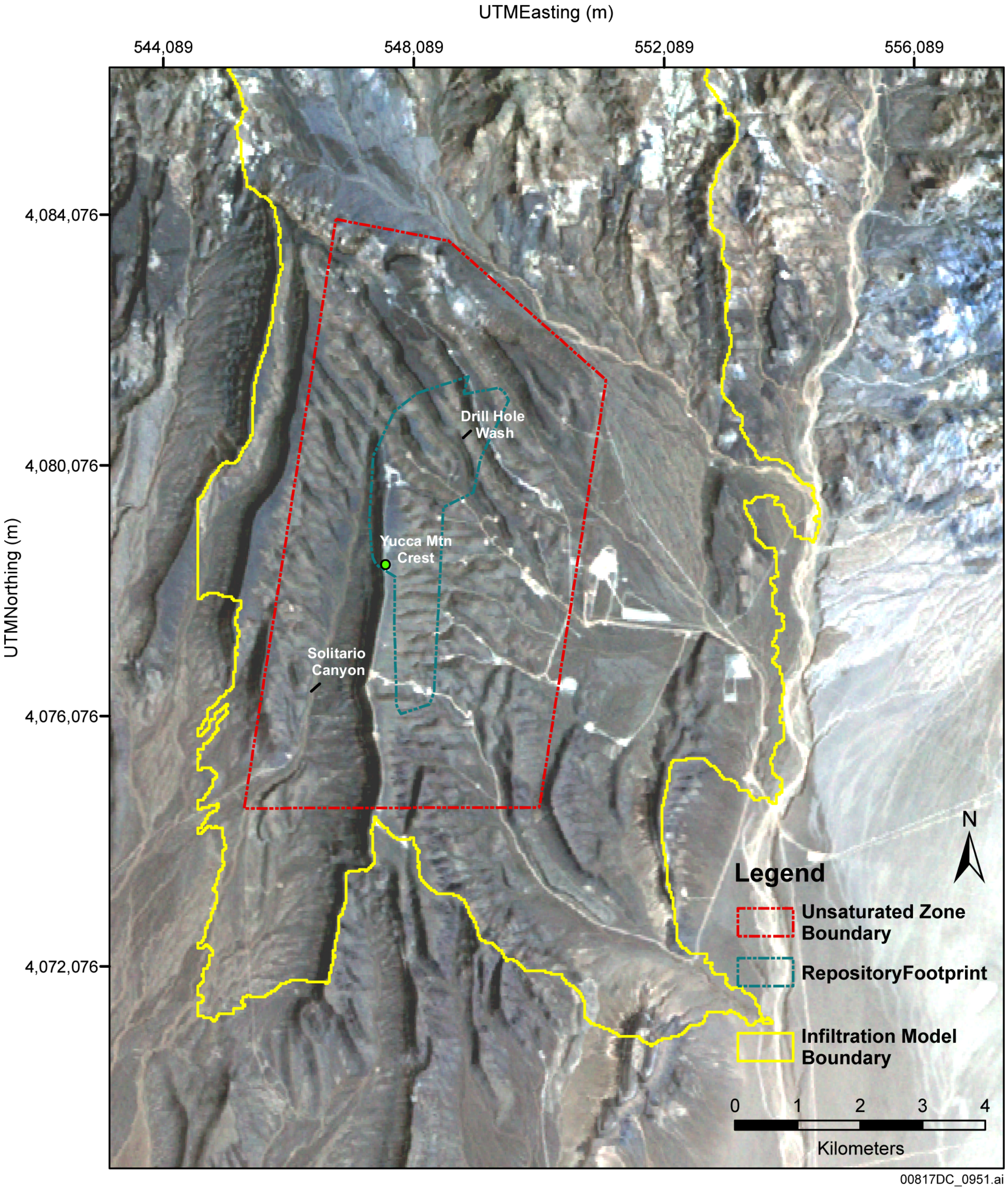
Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

Legend

- 🟩 Death Valley Regional Flow System model boundary
- ― Amargosa River drainage system

Source: Modified from BSC 2004 [DIRS 169734], Figure 8-2.

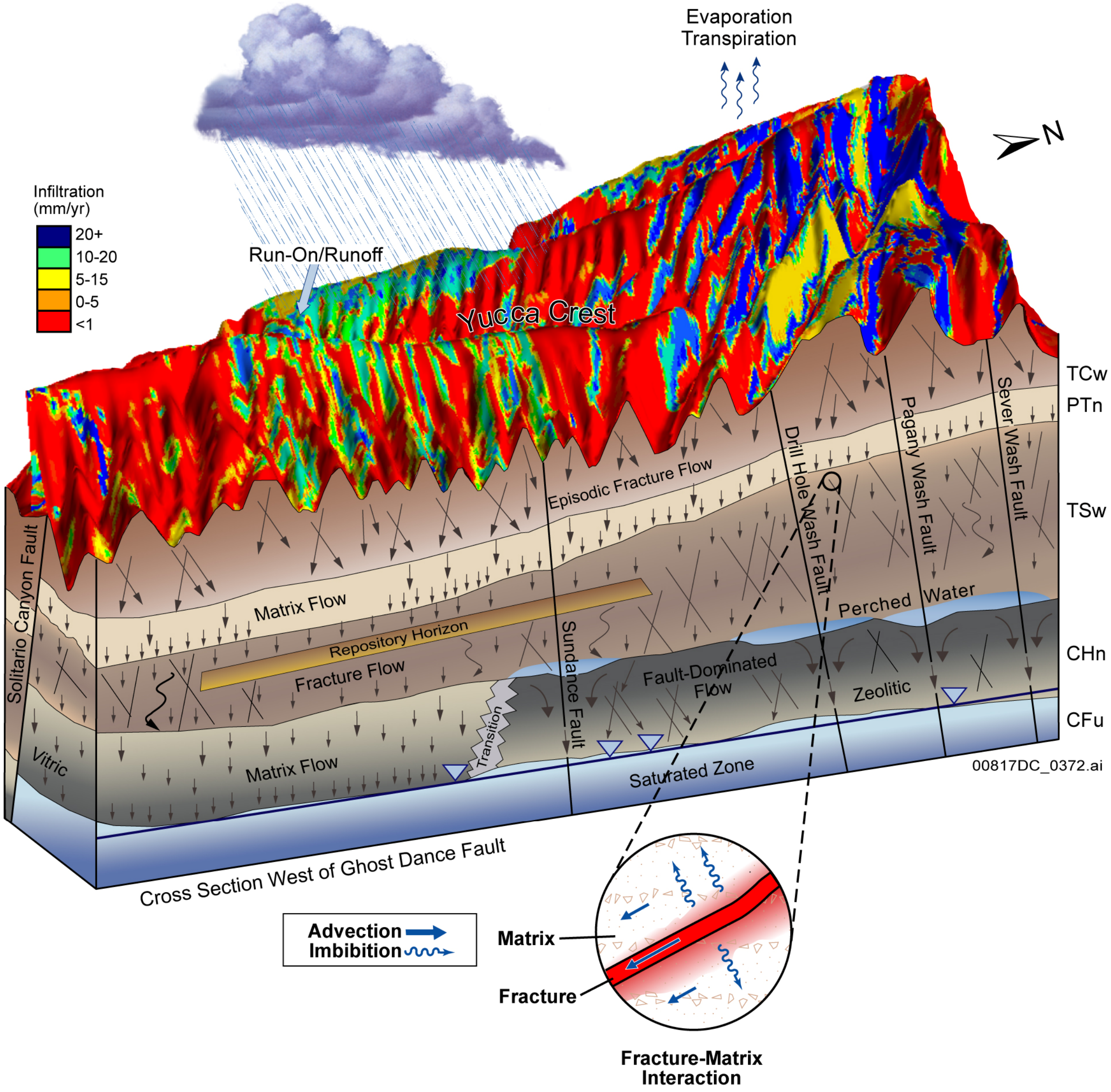
Figure 1-4. Geographic and Prominent Topographic Features of the Death Valley Region



Source: Modified from SNL 2007 [DIRS 182145], Figure 6.5.2.1-1[a].

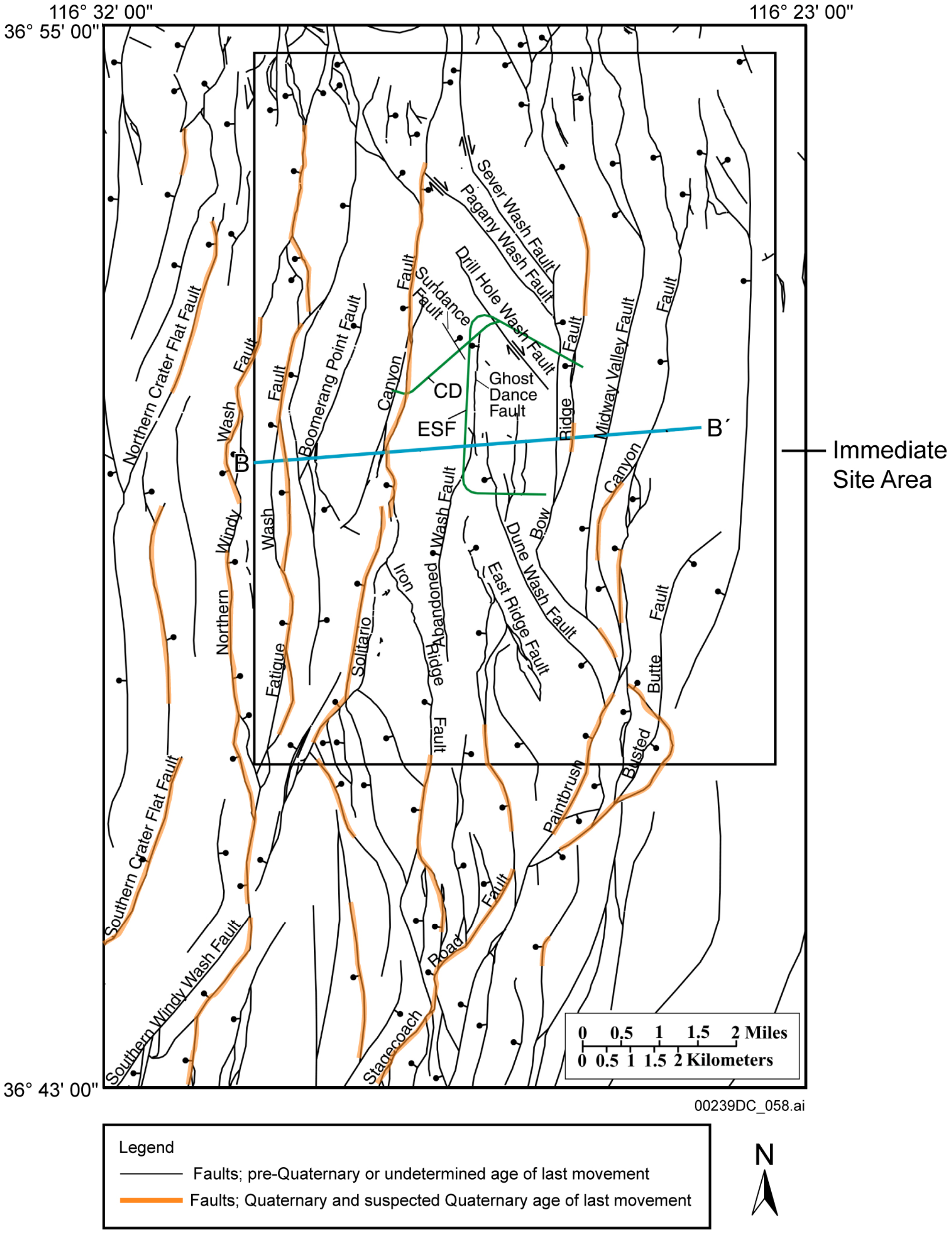
NOTE: The model boundary is the same as the 1999 unsaturated zone flow model domain of the TSPA-SR.

Figure 1-5. Topographic Map of the Yucca Mountain Site Showing Differences in Slope Characteristics North and South of Drill Hole Wash



Source: Modified from BSC 2004 [DIRS 170035], Figure 6-1.

Figure 1-6. Overall Water Flow Behavior in the Unsaturated Zone, Including the Relative Flux Magnitudes of Fracture and Matrix Flow Components in the Different Hydrogeologic Units

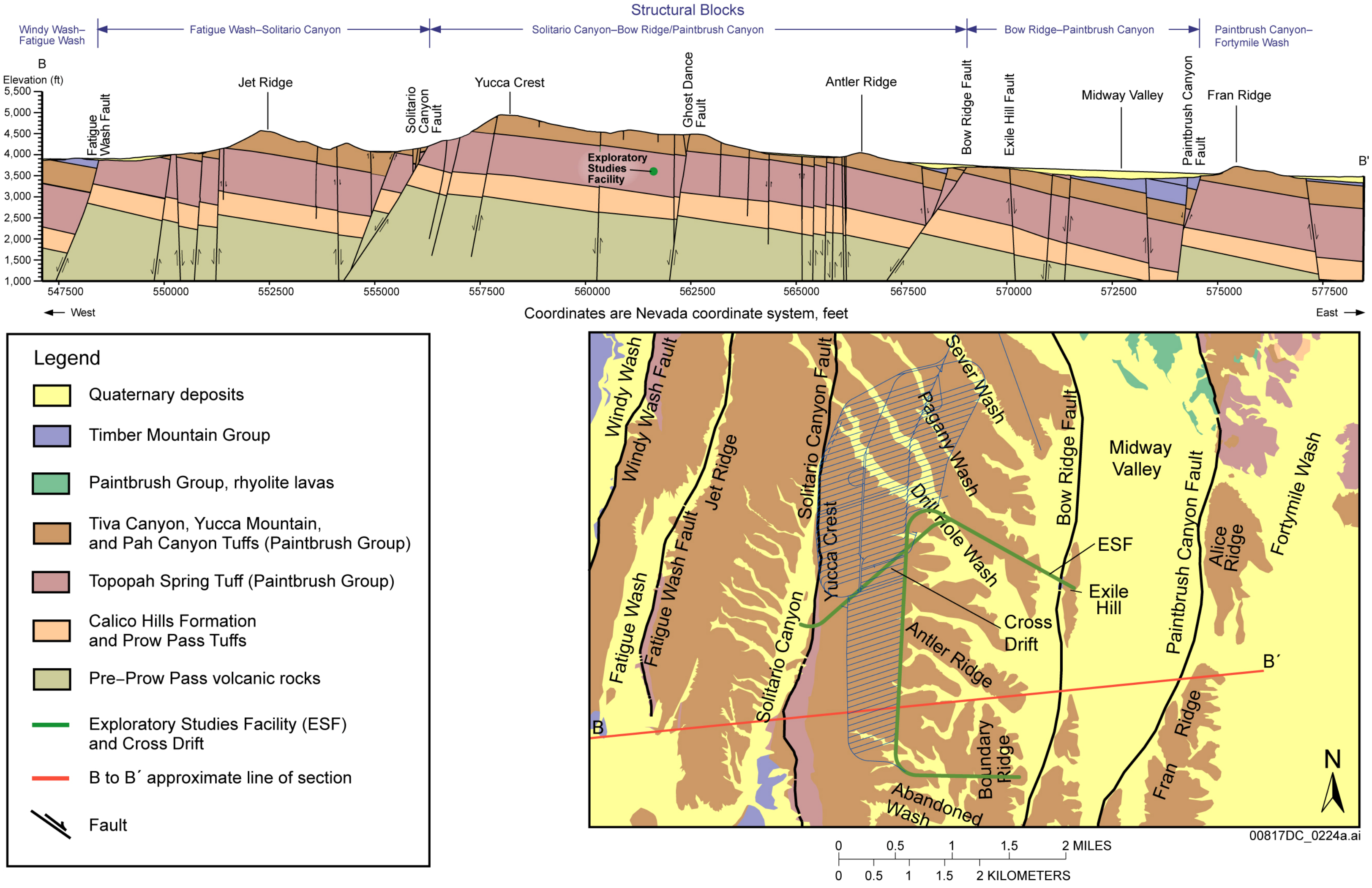


Source: Modified from BSC 2004 DIRS 169734], Figure 3-20.

NOTES: The following faults have demonstrable Quaternary activity: Northern Crater Flat Fault, Southern Crater Flat Fault, Northern Windy Wash Fault, Southern Windy Wash Fault, Fatigue Wash Fault, Solitario Canyon Fault, Iron Ridge Fault, Bow Ridge Fault, Paintbrush Canyon Fault, and Stagecoach Road Fault. All faults are shown with solid lines, although many segments are concealed or inferred.

Symbols and acronyms: bar and bell: downthrown side of fault; arrows: relative direction of strike-slip movement; ESF = Exploratory Studies Facility (green line); CD = Cross-Drift; blue line: approximate location of line of section shown on Figure 1-8.

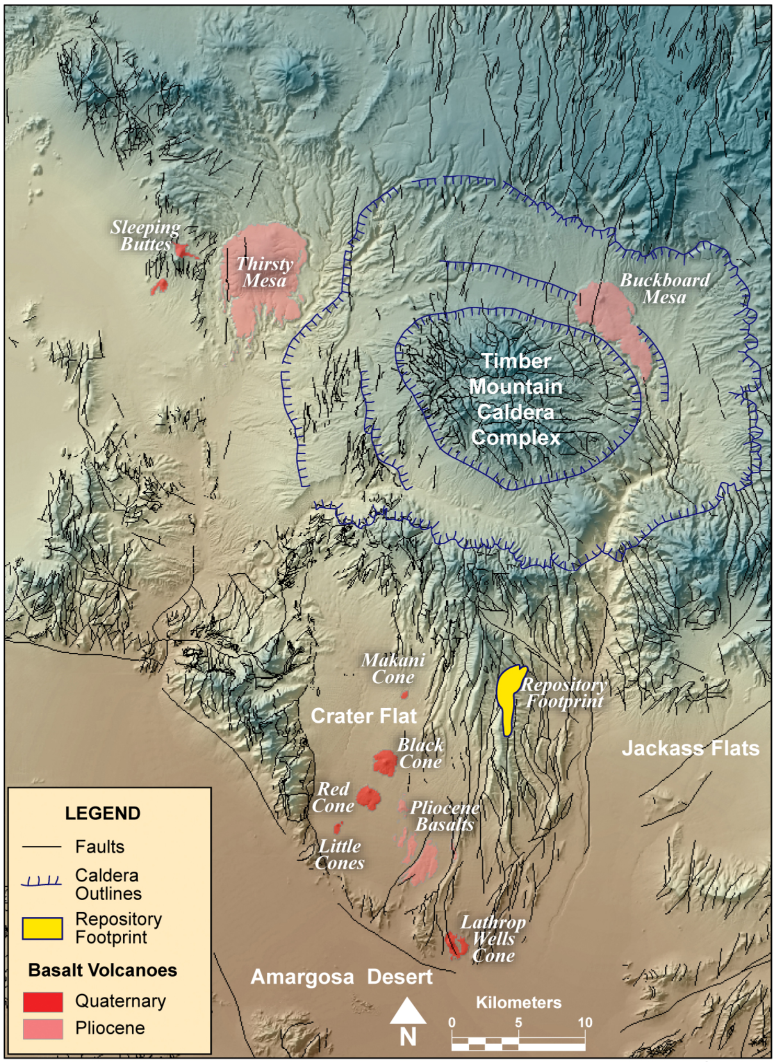
Figure 1-7. Distribution of Faults in the Yucca Mountain Site Area and Adjacent Areas to the South and West



Source: Simplified from Day et al. 1998 [DIRS 100027], Cross Section B-B'.

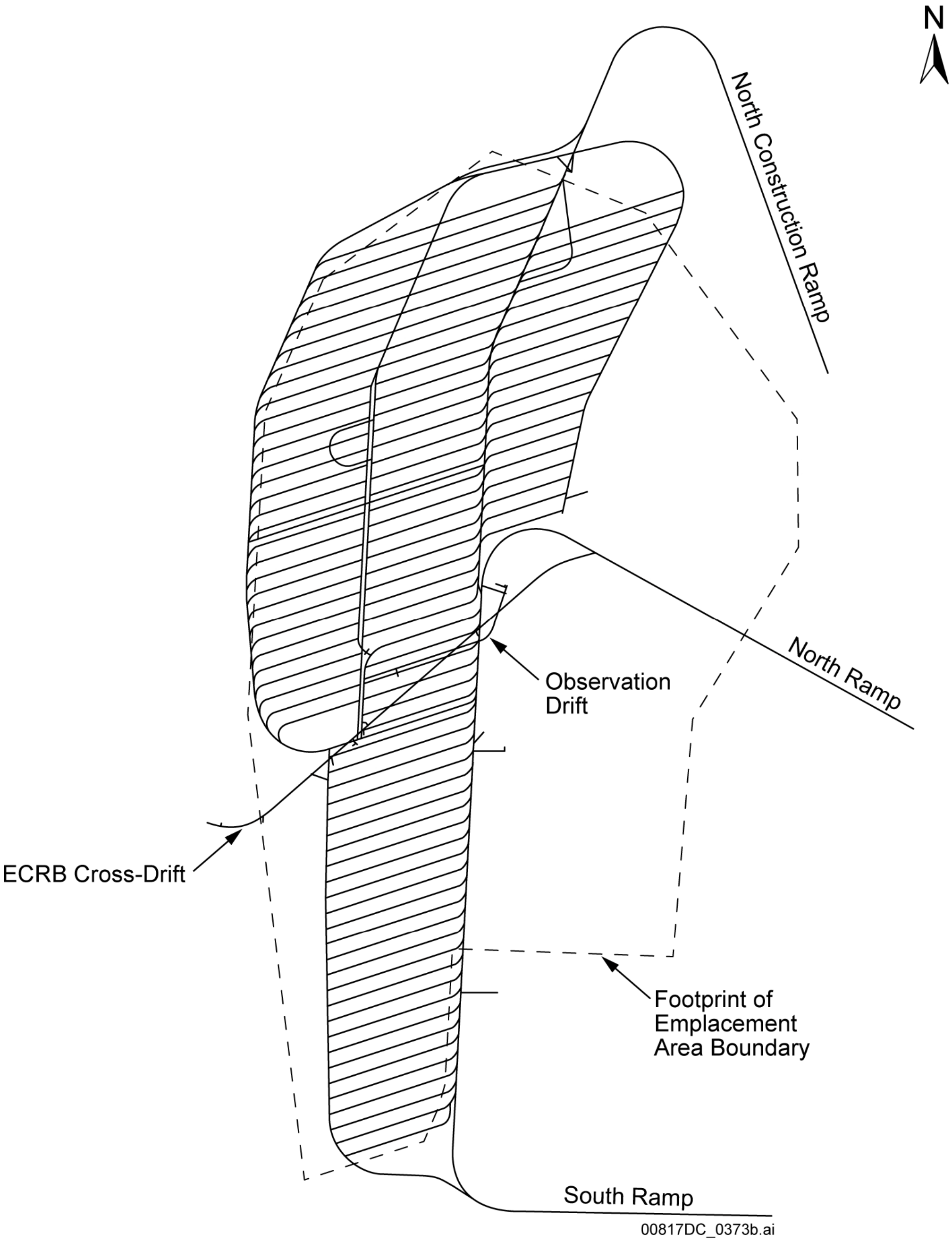
NOTE: ESF = Exploratory Studies Facility, location of intersection along the approximate line of section, also shown on Figure 1-7.

Figure 1-8. East-West Structure Section across Yucca Mountain Site Area



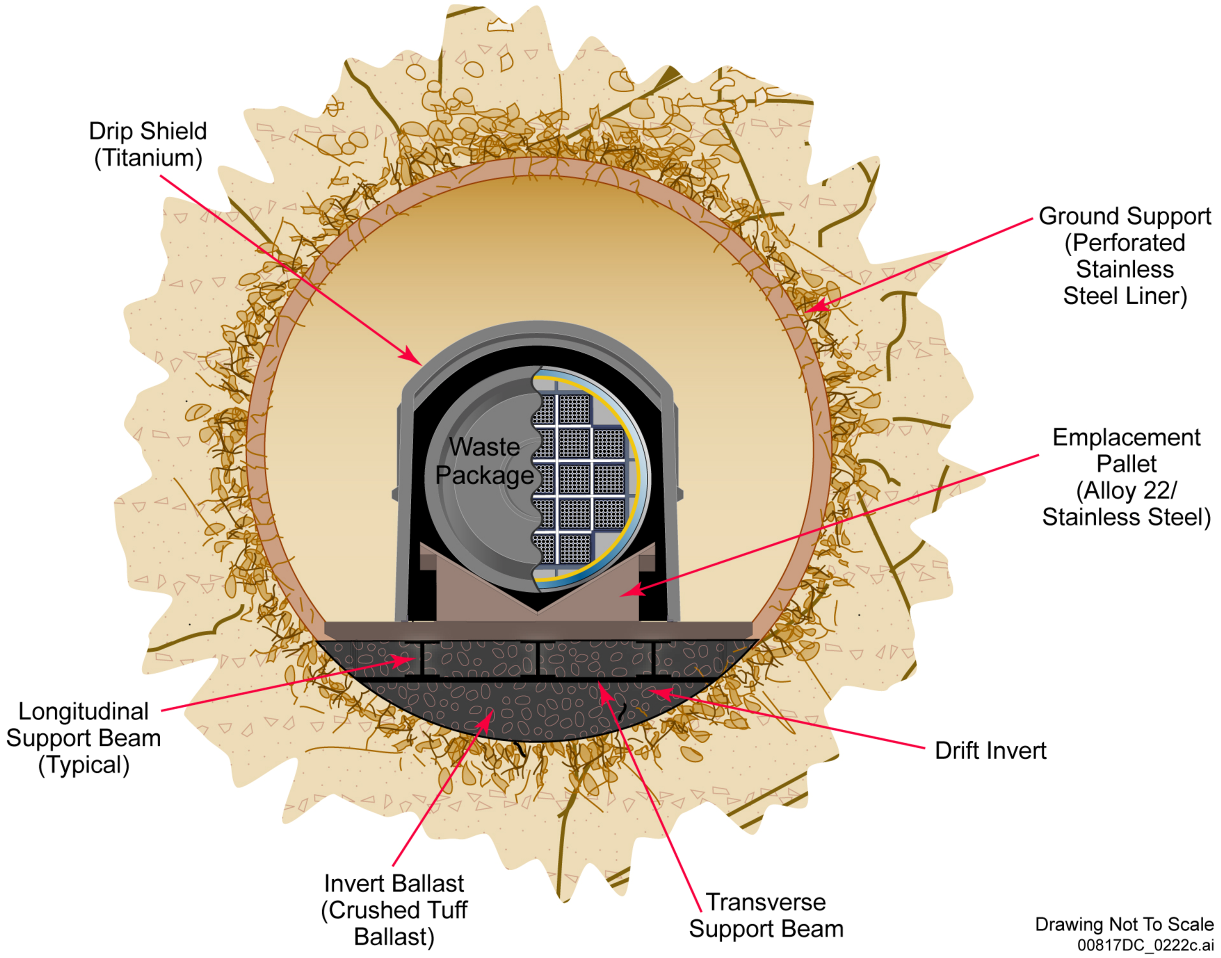
Source: Modified from CRWMS M&O 1998 [DIRS 123196], Figure 2.1.

Figure 1-9. Location and Age of Post-Miocene (less than 5.3 million years) Volcanoes (or clusters where multiple volcanoes have indistinguishable ages) in the Yucca Mountain Region



Source: Modified from SNL 2007 [DIRS 179466], Table 4-1, Parameter 01-02.

Figure 1-10. Subsurface Facility Layout



Source: Modified from SNL 2007 [DIRS 179354], Figure 4-1.

Figure 1-11. Cross Section Illustration of the Engineered Barrier System

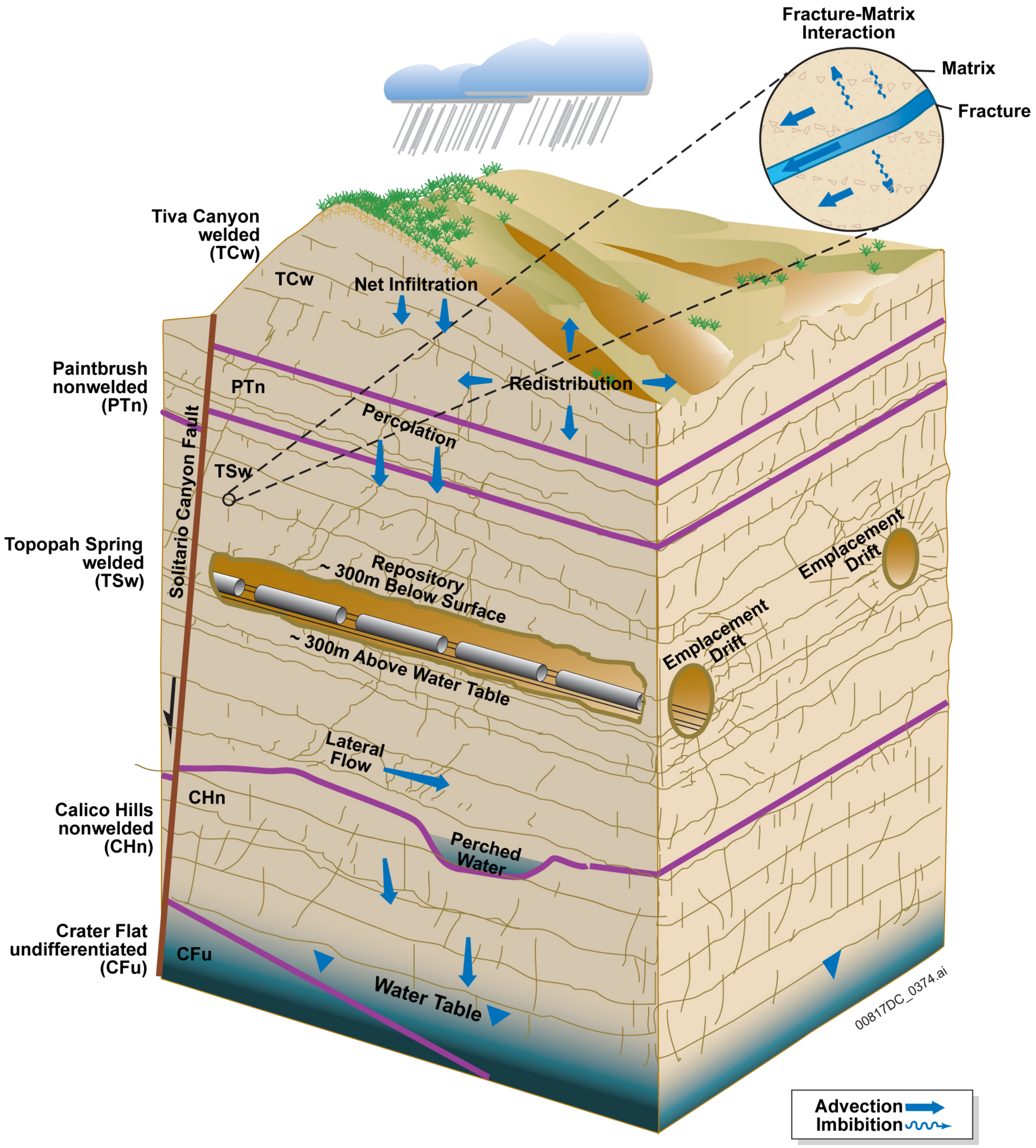


Figure 1-12. Conceptual Drawing of Mountain-Scale Flow Processes

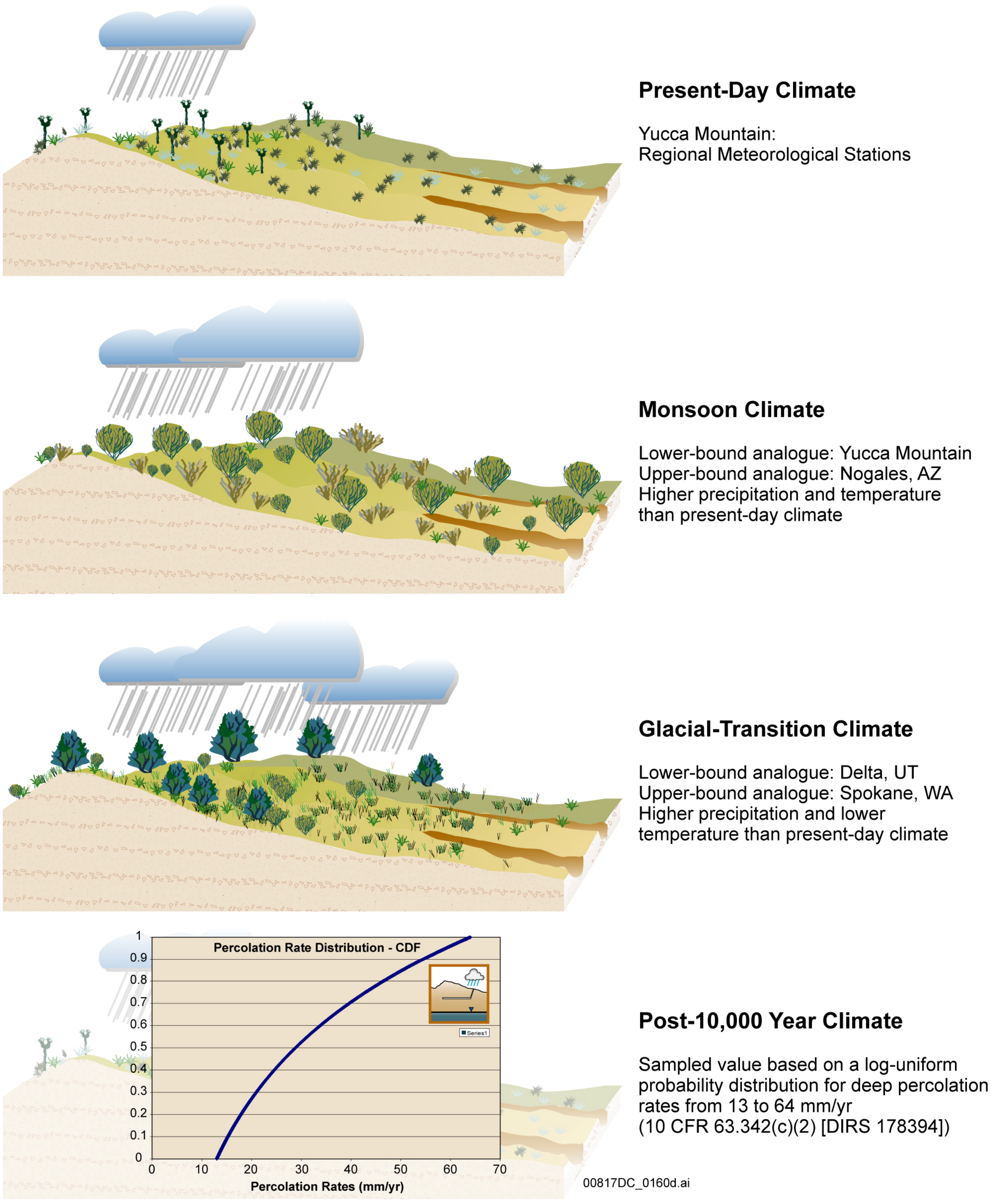
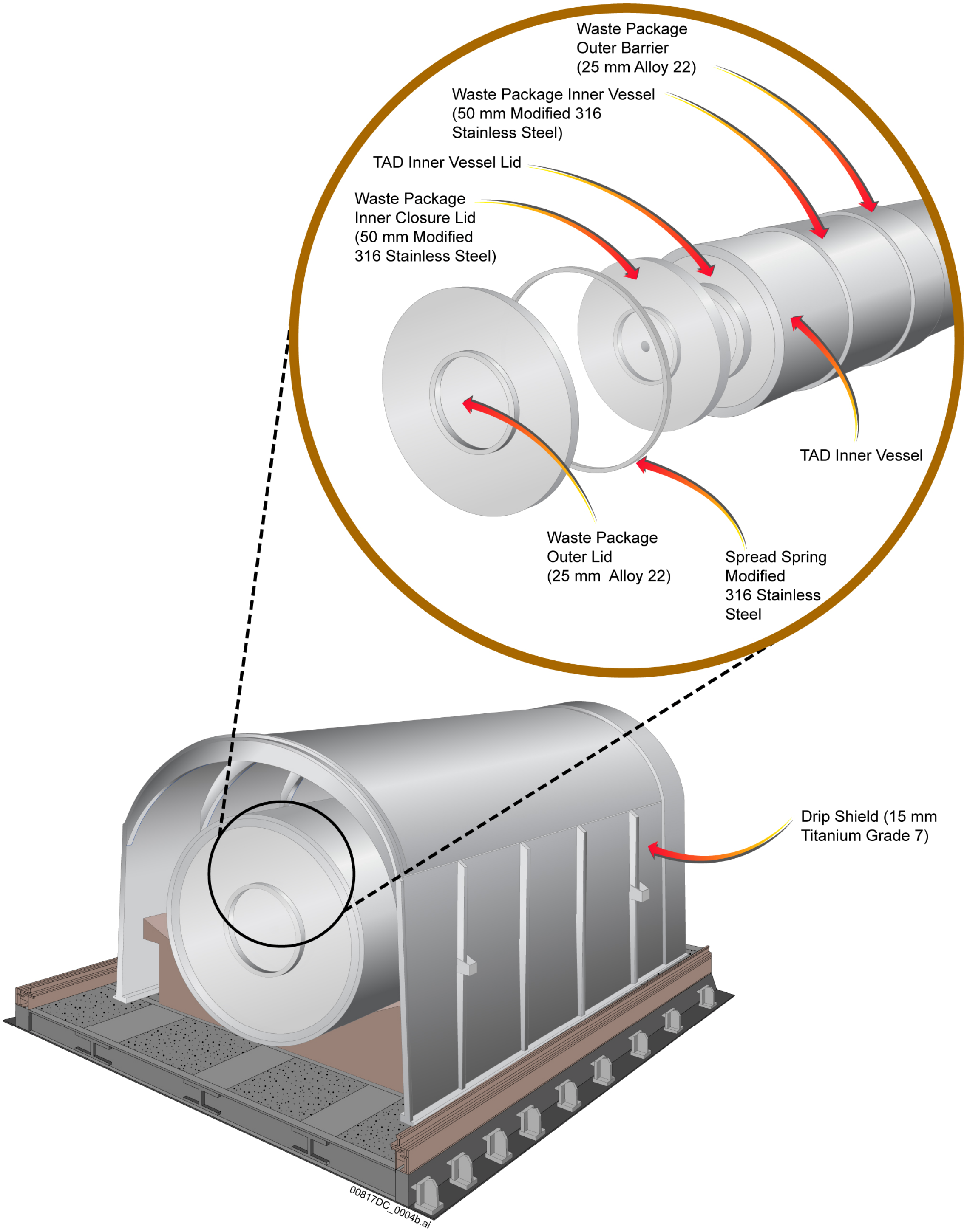
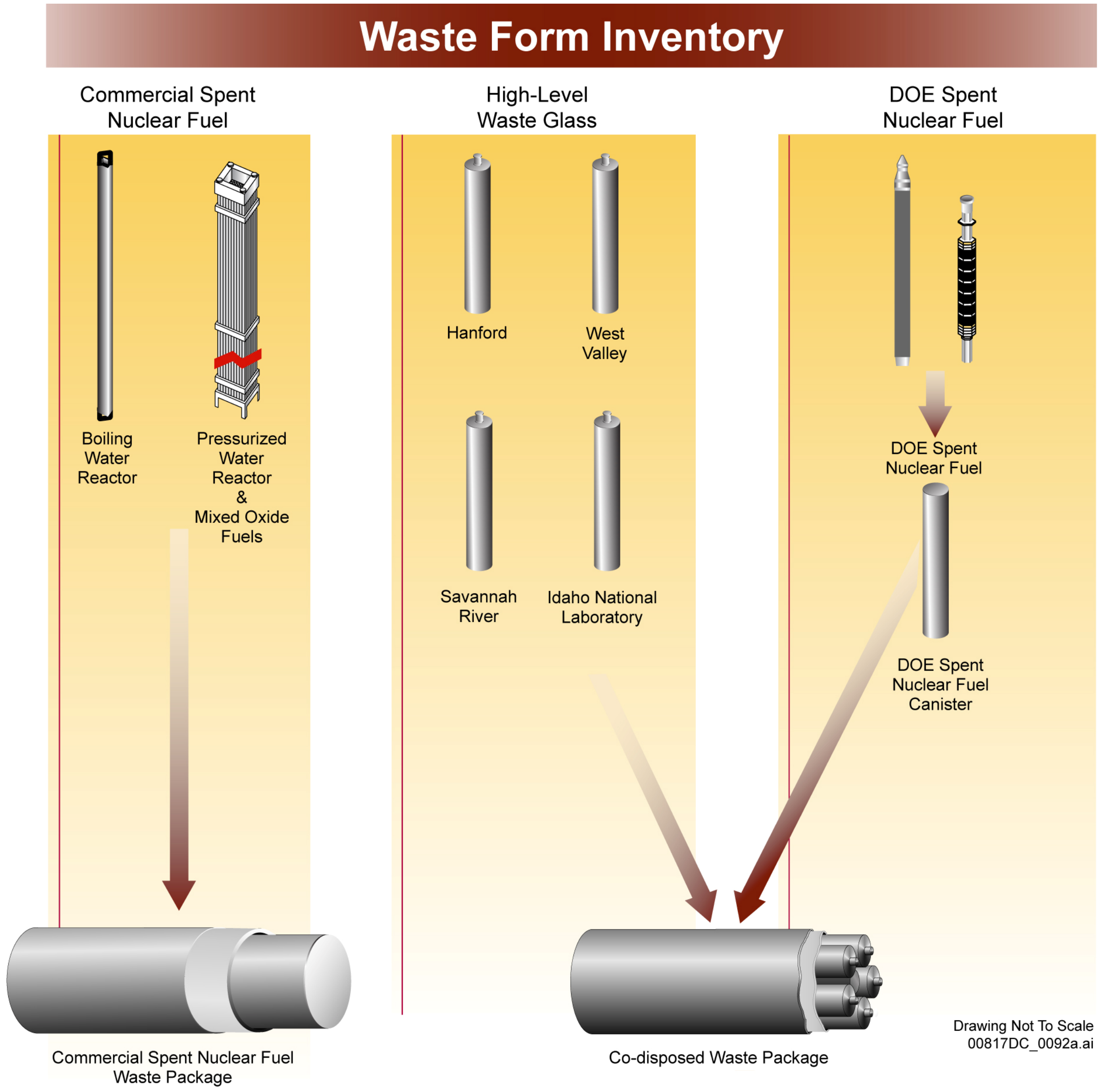


Figure 1-13. Illustration of the Four Climate Periods Used in the TSPA-LA Model and Analogues for the Monsoon and Glacial-Transition Climates



Source: SNL 2007 [DIRS 179394] and [DIRS 179354].

Figure 1-14. Schematic Design of the Drip Shield and Waste Package



Source: Modified from SNL 2007 [DIRS 180472], Figure 6-1.

NOTE: For modeling purposes, the naval waste packages are modeled as commercial waste packages.

Figure 1-15. Three Waste Types Grouped into Two Representative Waste Packages: CSNF and CDSP WPs

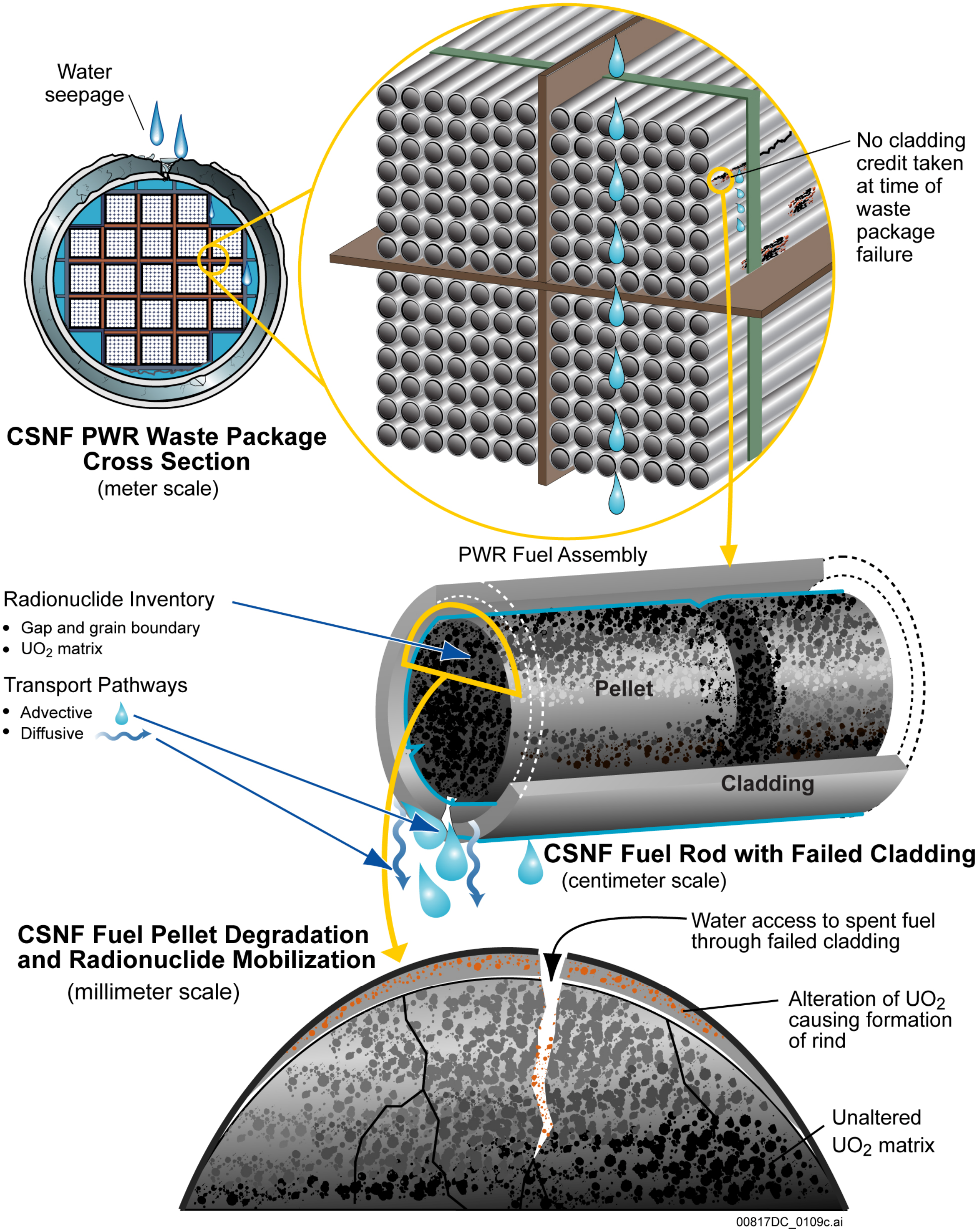
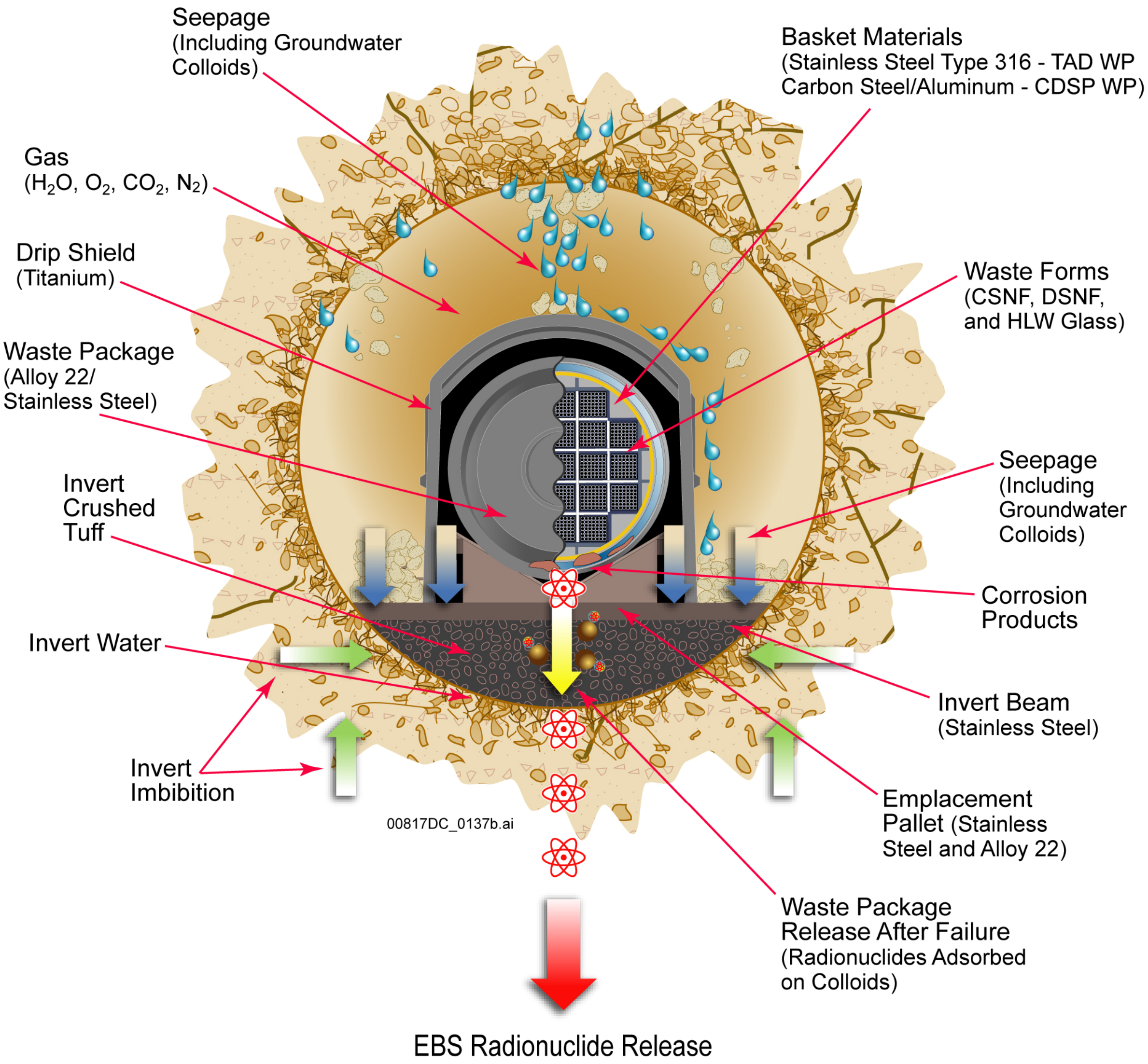


Figure 1-16. Schematic of CSNF Waste Form Degradation Mechanisms at Various Scales



NOTE: Discussion and analysis of the features and processes illustrated on this figure can be found in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6.1.1, Figure 6.1-1).

Figure 1-17. General EBS Design Features and Materials, Water Movement, and Drift Degradation

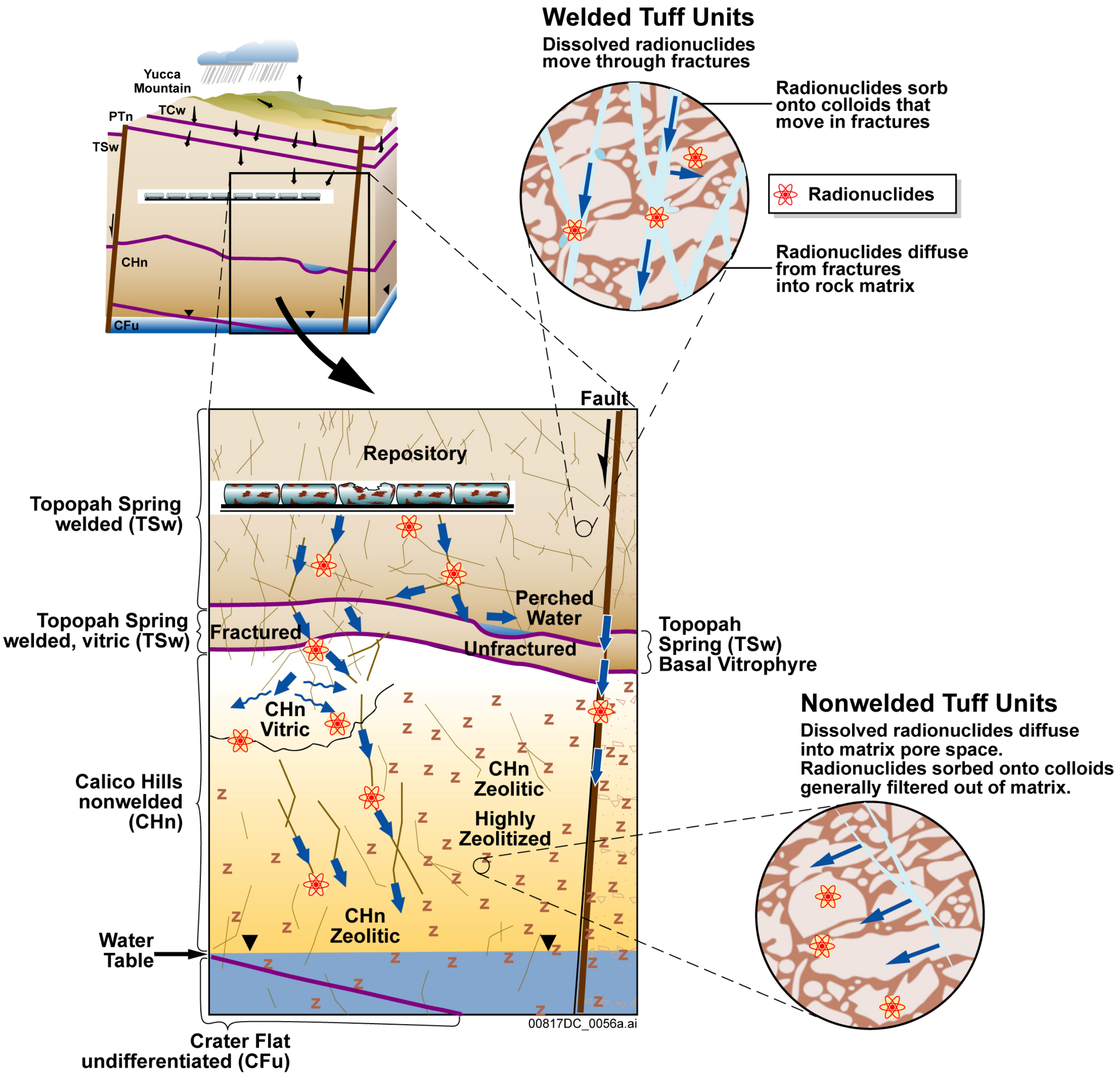


Figure 1-18. Conceptualization of Unsaturated Zone Transport Processes

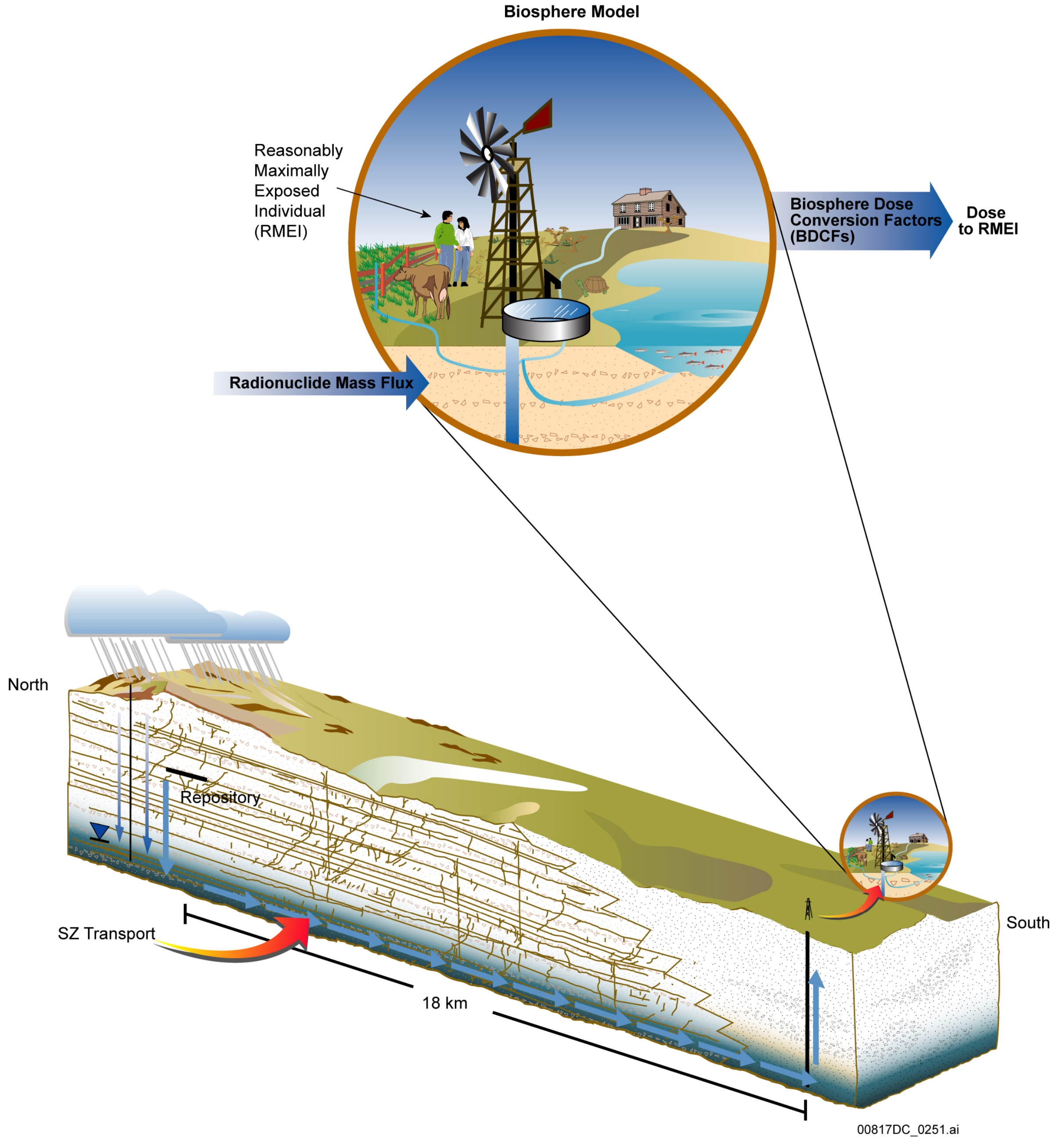
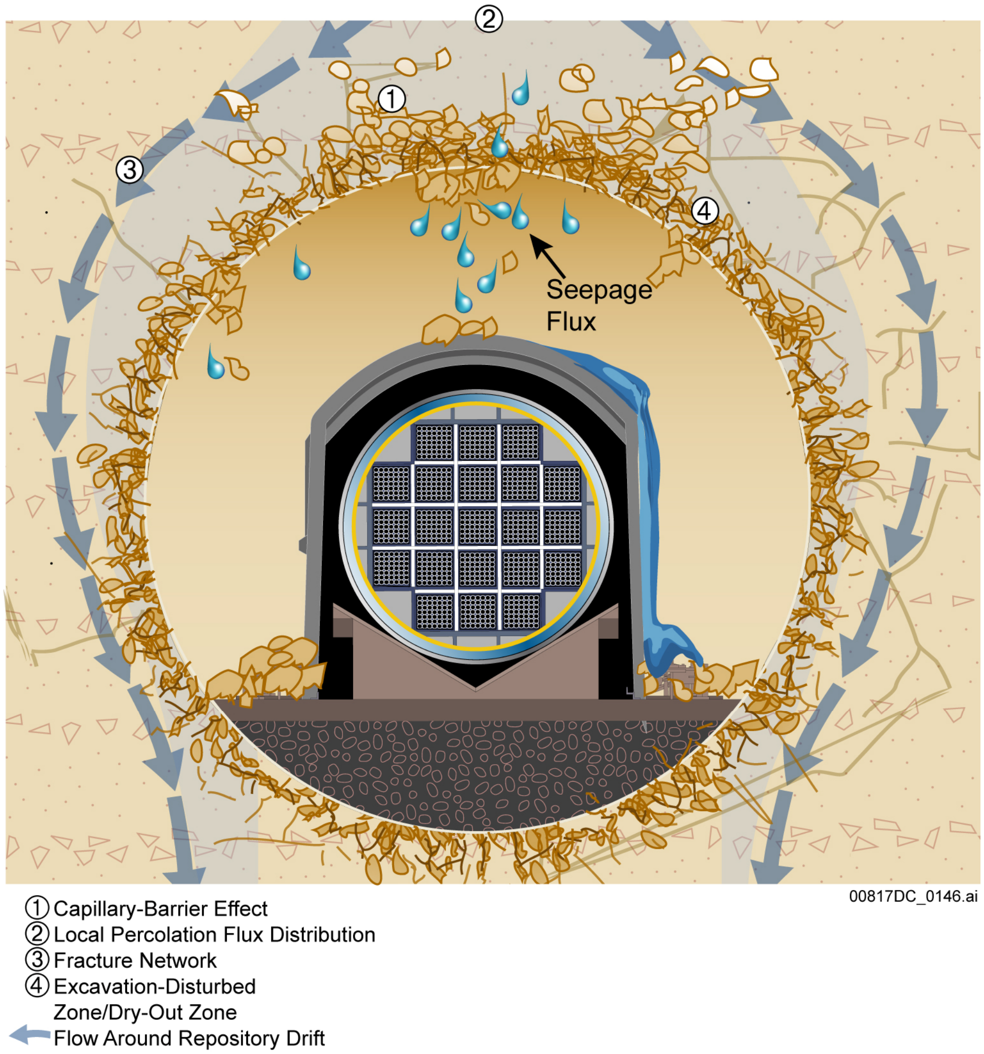
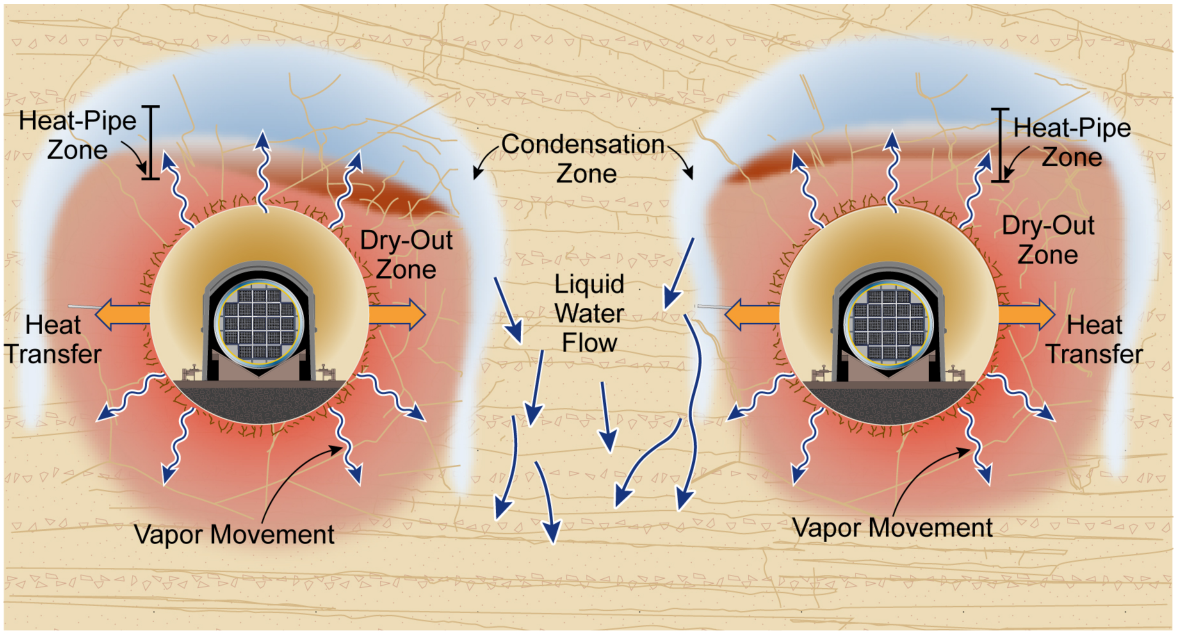


Figure 1-19. Overview of the Biosphere Groundwater Scenario Showing Groundwater Transport of Radionuclides and Uptake by the RMEI



Source: Modified from SNL 2007 [DIRS 181244], Figure 6.3-1.

Figure 1-20. Schematic Illustration of the Processes Affecting Ambient Drift Seepage



Source: Modified from BSC 2004 [DIRS 169734], Figure 5-81.

Figure 1-21. Schematic Illustration (not to scale) of Thermal-Hydrologic Processes in the Vicinity of the Emplacement Drifts Due to Repository Heating

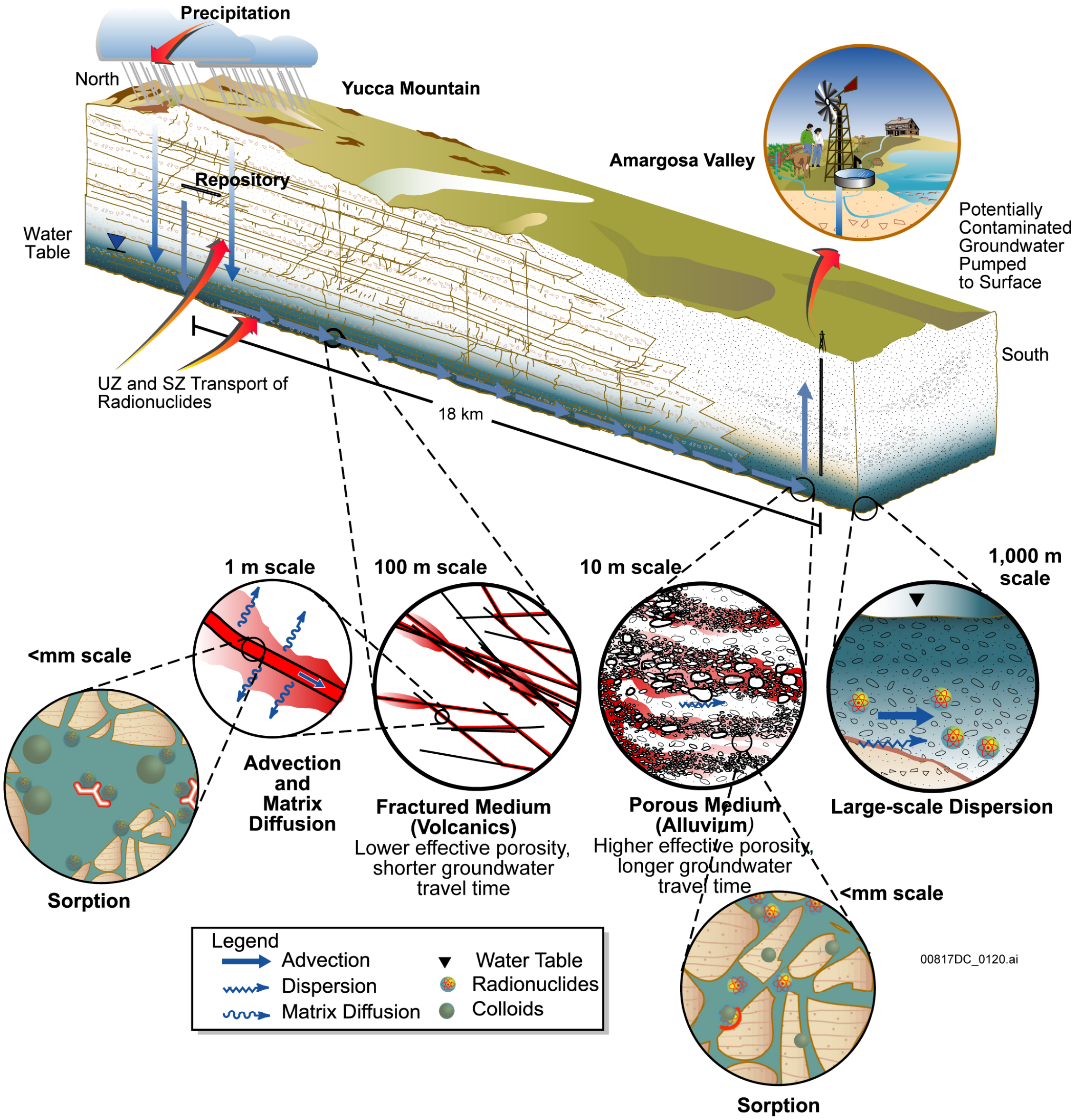


Figure 1-22. Conceptualization of Features and Processes Important to Saturated Zone Transport

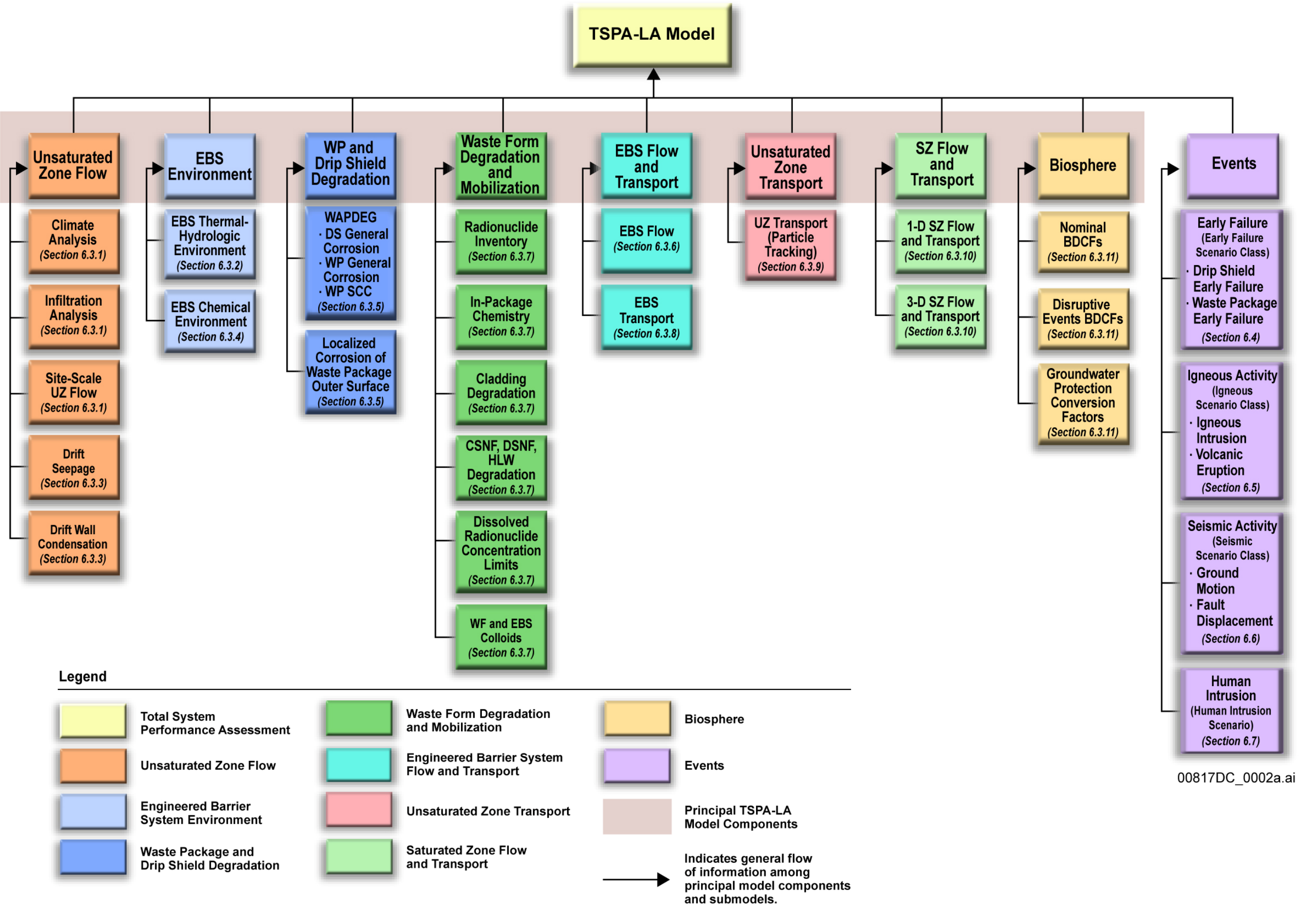


Figure 1-23. TSPA-LA Principal Model Components and Submodels

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2. QUALITY ASSURANCE

The OCRWM QA program is first codified and implemented in the *Quality Assurance Requirements and Description* (QARD) (DOE 2007 [DIRS 182051]). The QARD applies to this technical product.

Technical Work Plan for: TSPA-LA FY 07-08 Activities (SNL 2008 [DIRS 184920]) describes in more detail the implementation of the QA program and contains the following:

- The conclusion that the work scope related to the completion of this technical product is subject to the requirements of the QARD (DOE 2007 [DIRS 182051])
- The list of QA procedures used to complete this technical product
- The processes used to control the electronic management of data used to complete this technical product.

2.1 CONFIGURATION MANAGEMENT

The development of the TSPA-LA Model required organization, control, and accountability. In the language of Configuration Management, this translated into implementing the following four processes:

1. **Configuration Identification**—This is the unique identification of all the items to be managed in the system. Configuration identification consists of selecting the items to be managed and recording their functional and physical characteristics.
2. **Configuration Change Control**—This is the mechanism used to approve or disapprove all proposed changes to the system that is being managed. Configuration change control ensures that changes to any configuration items are approved and controlled so that consistency among components is maintained.
3. **Configuration Status Accounting**—This is used to ensure that information contained in the status accounting system documents the evolution of the TSPA-LA Model in a transparent and traceable manner.
4. **Review**—The review process checks the configuration items to verify that they are uniquely identified, described, and managed in the system.

The software development procedures (i.e., IM-PRO-003, *Software Management*; IM-PRO-004, *Qualification of Software*; IM-PRO-005, *Software Independent Verification and Validation*; and IM-PRO-006, *Software Independent Verification and Validation of Legacy Code*) implement these Configuration Management processes for software development. However, to efficiently manage the development of the TSPA-LA Model, the same configuration management processes (e.g., Configuration Identification and Configuration Change Control) mentioned previously were used in the form of workplace controls. Summaries of the controls placed on software development, model development, and input development are provided in the sections that follow.

2.1.1 Configuration Management of Software

All software codes used to support the TSPA-LA Model were qualified in accordance with project software development procedures. These procedures establish the roles and responsibilities for the organizations responsible for implementing the four configuration management processes described previously. The first three processes below were administered by the SCM organization. The fourth process below was administered by the Software Independent Verification and Validation organization.

1. **Configuration Identification**—Each piece of software and its supporting documentation was uniquely identified with a software tracking number (STN) and document number, respectively.

2. **Configuration Change Control**—After software was qualified in accordance with the software development procedures and placed on the software baseline, only then approved changes were made.

3. **Configuration Status Accounting**—This process kept track of the status of software during software development and operations. The following are examples of the items tracked: (a) descriptions of the primary function of the software; (b) versions of documents and media; (c) software users; (d) software status, such as active, retired, or canceled; and (e) descriptions of operating platforms and systems.

4. **Review**—The details of the review process are established in IM-PRO-005, *Software Independent Verification and Validation* (for earlier code qualifications, LP-SI.13Q-BSC, *Software Independent Verification and Validation,* and AP-SI.3Q, *Software Independent Verification and Validation*). This review ensures that software requirements are adequately written and traced through the software documentation and that each requirement is verified by validation testing. Additionally, the review ensures that the documentation is reviewed by a qualified individual without recourse to the originator.

The specific codes used in the TSPA-LA Model are discussed in detail in Section 3. Section 3 also expands the discussion of the SCM functions mentioned in Items 1 through 3.

2.1.2 Configuration Management of the Development of the TSPA-LA Model

The development of the TSPA-LA Model required modifications from time to time for a number of reasons. This section presents the management control system that was implemented to track and maintain a record of these changes, as illustrated on Figure 2-1.

New or revised analysis and/or model reports were developed for the TSPA-LA. During the development of new or revised analysis and/or model reports, the TSPA Analysts consulted with the SMEs to define the technical output of their analysis and/or model reports for use in the TSPA-LA Model. Draft information, such as preliminary DTNs and preliminary TSPA Data Input Packages, was provided for initial implementation and inserted into the TSPA-LA Model. This information included relevant process models, model abstractions, and submodels that are contained in the analysis and/or model reports. The appropriate SMEs have reviewed the results of the initial implementation to ensure that the implementation is consistent with each SME's intent. Discrepancies were addressed by changing the implementation of the submodels or model abstractions in the TSPA-LA Model and/or by changing the supporting analyses and/or model reports and/or DTNs prior to their approval.

In addition, new or revised analysis and/or model reports developed for the TSPA-LA Model were reviewed by the TSPA Department according to SCI-PRO-003, *Document Review.* Part of this review determined whether or not changes to the TSPA-LA Model were needed and if the changes were within the TSPA-LA Model development scope and schedule.

Internal TSPA-LA Model changes, such as a change in model logic to select specific parameters for individual modeling cases, were identified as part of TSPA-LA Model development. The TSPA Department Manager reviewed and approved changes to the TSPA-LA Model development scope and schedule to accomplish required revisions to the analyses and/or model reports and/or the TSPA-LA Model inputs developed by the analysis and/or model reports. Changes outside the TSPA-LA Model development scope and schedule elevated the issue(s) to the appropriate management level for resolution. Management approval of changes to the TSPA-LA Model were based in part on whether or not a change was necessary to comply with regulatory requirements, regardless of the final input feed date for the requested change, or whether the TSPA-LA Model was finalized or frozen for performing TSPA-LA analyses.

Changes to the TSPA-LA Model were tracked by the TSPA Department. Figure 2-2 shows the TSPA Model Change Approval Form used to track the changes to the TSPA-LA Model. During the development stage of the TSPA-LA Model, TSPA Analysts were required to obtain written approvals from the TSPA Department Manager, TSPA Model Calculations Lead, and TSPA Configuration Management Lead, to change and/or introduce new process models, model abstractions, or parameters into the TSPA-LA Model. The written authorization specified the source(s) (e.g., analysis and/or model reports, DTNs) of the process models, analyses models, model abstractions, or input parameters.

Another important aspect regarding the control of the TSPA-LA Model is ensuring consistent, well-documented inputs. The supporting organizations provide abstractions and technical product output to the TSPA-LA Model according to a scope and schedule review. The most recent scope and schedule reviews were led by the Performance Assessment System Integration Team. The reviews resulted in the addition of detailed requirements and specifications to the TWPs for each work package containing an analysis and/or model report. Additional requirements were incorporated into revisions to the TWPs that specified content for FEPs, ACMs, parameters, and characterization of uncertainty for the TSPA-LA Model.

Additional product management emphases and controls included:

- A consistent model hierarchy and structure supporting the TSPA-LA Model architecture
- A consistent treatment and documentation of model abstractions supporting the TSPA-LA Model
- A consistent treatment and documentation of ACMs

- A consistent treatment and documentation of FEPs included in the TSPA-LA Model, as well as how the FEPs were included and where their inclusion was documented
- A consistent evaluation of the definition and performance of the natural and engineered barriers of the repository system and the basis for the projection of barrier performance
- A consistent evaluation of parameter uncertainty and how that uncertainty is propagated through the model hierarchy to the TSPA-LA Model and how the significance of that uncertainty is evaluated
- A consistent documentation of how the TSPA-LA Model components and submodels are integrated and how the information flows between the submodels and the analyses, including roadmaps of information supporting the TSPA-LA Model
- A consistent basis for determining the appropriate amount of confidence required for model validation
- A consistent evaluation of the parameter values that were used to develop parameter distributions and why those parameter values are sufficient to capture the range of possible observations.

The above emphases determined much of the content of the analysis and/or model reports that support the TSPA-LA Model and postclosure safety case for presentation in the LA. These analysis and/or model reports remain the primary supporting documentation for the TSPA-LA Model. Updated TWPs for each of the supporting analysis and/or model reports ensured that the scope was assigned appropriately (i.e., FEP by FEP, model by model, and parameter by parameter).

The more detailed scope definitions that resulted from the above process yielded a much more consistent and comprehensive treatment of, not only parameter uncertainty, but also FEP uncertainty and ACM uncertainty. The process also allowed for early definition of the scope and content of the TSPA-LA Model within the context of the document, as agreed to in several Total System Performance Assessment Integration Key Technical Issue agreements. This more detailed scope definition has allowed the authors of analysis and/or model report authors to focus on the key performance-related aspects of their models and analyses in a more risk-informed way.

Physical Control of Files—The TSPA-LA Model input files, DLLs, and the database were controlled by their storage in a set of controlled subdirectories on the TSPA file server.

Input Files—Input files for the TSPA-LA Model were stored in a controlled subdirectory on the TSPA file server. Read access to this subdirectory was limited to the TSPA Department staff. Write access was limited to the TSPA-LA Configuration Management staff and the System Administrator. The TSPA-LA Configuration Management staff established a baseline list of files. Any subsequent changes to the input files were documented as changes to the baseline list.

DLLs—DLLs for the TSPA-LA Model were obtained from SCM and installed in a controlled subdirectory on the TSPA file server by the TSPA-LA Configuration Management staff. Read access to this subdirectory was limited to the TSPA Department staff. Write access was limited to the TSPA-LA Configuration Management staff and the System Administrator. The TSPA-LA Configuration Management staff established a baseline list of DLLs, and any subsequent changes to the DLLs were documented by the TSPA-LA Configuration Management staff as changes to the baseline list.

Input Parameters—Both fixed-value and uncertain input parameters for the TSPA-LA Model were controlled in the TSPA Input Database described in Section 4.4. The database was stored in a controlled subdirectory on the TSPA file server. Read access to this subdirectory was limited to the TSPA Department staff. Write access was limited to the TSPA-LA Configuration Management staff and System Administrator. Changes to the database were controlled via the change control and checking process used for the TSPA-LA Model.

Change Control and Checking—Table 2-1 summarizes the forms, checklists, descriptions, and logs used to manage the change control and checking of the TSPA-LA Model.

The TSPA-LA GoldSim model file was checked by qualified individuals assigned by the TSPA Model Calculations Lead. The checker for a model change and/or model run is another TSPA Analyst who was not involved in modifying the model file or input file(s).

Two types of checks were performed on updated versions of the TSPA-LA GoldSim model file: implementation checking and conceptual model checking. Implementation checking verifies that all of the changes to the TSPA-LA Model file and/or external files were performed correctly. Conceptual model checking considers whether the TSPA-LA Model implementation correctly reproduces the conceptual process model or model abstraction from the associated analysis and/or model report, submodel, or scientific analysis.

Implementation Checking—Implementation Checking was completed by reviewing the changes identified by the analyst in a checklist similar to Figure 2-3 and then documenting completion to the following steps in a second checklist similar to Figure 2-4. The primary steps involved in Implementation Level checking included:

- Checking modified GoldSim elements against their source information to verify that they were changed correctly
- Verification that the input links of added elements were correct
- Verification that the output links of added parameters were correct
- Checking that the links to and from any deleted elements were appropriately reconnected
- Verification (by inspecting source references for changes) that each change to an external file was correct.

Concept Level Checking—The Concept Level Checking process considers whether the changes to the TSPA-LA Model correctly reflect conceptual model changes using a checklist similar to Figure 2-5. The conceptual description includes a general description of changes made to the TSPA-LA Model. Any development and testing work to support changes to the TSPA-LA Model were documented in the conceptual description.

Any differences between the results of the initial and modified modeling case(s) were explained and properly documented by the checker and/or analysts in terms of the changes made to the TSPA-LA Model.

The details of the Implementation and Concept checks are described in a series of Desk Guides used by the TSPA Department. The completed Desk Instruction forms are contained in the output DTNs for the TSPA modeling runs listed in Section 8.

2.1.3 Configuration Management for the TSPA-LA Model Input

The TSPA-LA Model was developed by making incremental changes to the TSPA Final Environmental Impact Statement Model (Williams 2001 [DIRS 157307]). Each of these incremental changes had a set of input files and parameters that were saved and/or archived on the designated TSPA Department server. The DLLs and their associated input files were not embedded in the TSPA-LA Model file but were saved or archived separately as file sets, whereas the input parameters used for each TSPA-LA Model run were captured in each of the incremental TSPA-LA Model files and in the final TSPA-LA Model file, upon which this document is based. The TSPA-LA Model file and all associated inputs were submitted to the TDMS database in accordance with TST-PRO-001, *Submittal and Incorporation of Data/Technical Information to the Technical Data Management System*.

The input files are necessary to run each of the DLLs. The DLL input files used during the development of the TSPA-LA Model were numbered (e.g., Input File Set 1, Input File Set 2, and so on). The Input File Set used for each model change was documented on the TSPA-LA Model Change Approval Form (Figure 2-2). An electronic copy of each file set was saved on the designated TSPA Department file server (see Appendix F for detailed information on DLL input files).

The TSPA Input Database, which is described in Section 4.7, is electronically linked at run time to the TSPA-LA Model. The TSPA Input Database is a controlled warehouse of all of the input parameters used to run the TSPA-LA Model. An important configuration management feature of the TSPA Input Database is that the TSPA Input database supports the independent verification of every value used in the TSPA-LA Model. For example, a TSPA Analyst is assigned the task of verifying that for a given parameter value or set of values, the reference information used to find the value is within the reference. Once the TSPA Analyst has confirmed the value in the database is the same as the value in the reference, then the TSPA Analyst clicks a verification button in the TSPA Database for the given parameter, thereby indicating that the parameter is verified. If the parameter value or reference information is edited, then the TSPA Input Database indicates that the parameter is no longer verified. The TSPA Input Database verification feature ensures that any preliminary input parameters are confirmed to be consistent with the formal reference such as an analysis and/or model report or DTN.

The parameter values are obtained from controlled sources maintained by the project data and information systems, such as project documents, TDMS, and Technical Information Center. The TDMS database is a project-wide database, whereas the TSPA Input Database is used only for the TSPA-LA Model. Each of the parameter sets used in the TSPA Input Database has a DTN to provide the link to the TDMS database or a reference to the controlled source of the information, such as an analysis and/or model report. The TDMS maintains the qualification status of all of its contents. In closing, the TSPA Model inputs are controlled and well documented by using the TSPA Input Database. Additional details on the control and documentation of the sources of the data can be found in Section 4.

2.2 MODEL VALIDATION

The assessment of the validation status of the TSPA-LA Model for its intended use is based on: (1) the compilation of the information developed according to the activities documented in Section 7 following criteria in SCI-PRO-006, *Models*; (2) the summary of the validation work developed by the Independent Technical Reviewer (ITR); and (3) the determination of the Performance Assessment Systems Integration Manager.

The ITR is required per SCI-PRO-006 (Section 6.4.12) to provide a review of the model validation documentation (Volume 2, Section 7) and then document the review. The documentation must include the validation criteria and the information used in determining whether the criteria were met.

SNL (2008 [DIRS 184920], Section 2.3.5) indicates that the final determination regarding model validation is made by the Performance Assessment Systems Integration Manager:

> The complete body of information developed for validation of the TSPA-LA model, including the process model validation information for the supporting submodels, will be provided to the Performance Assessment Systems Integration Manager for determination of the model's validation status.

The signature of the Performance Assessment Systems Integration Manager on this document signifies that the TSPA-LA Model is found valid for its intended purpose.

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Table 2-1. Configuration Control Documents for the TSPA-LA Model

Figure Number	Name	Purpose
2-2	TSPA-LA Model Change Approval Form	Provides management control of all changes to the TSPA-LA Model. Summarizes the extent of the change.
2-3	TSPA-LA Model Changes Checklist	Initiated by the TSPA analyst. Documents the specific changes made to the TSPA-LA Model (parameter checking). Checker uses this list of changes to check.
NA	Conceptual Description	Provides overview of the changes that were incorporated into the TSPA-LA Model. May also include development and checking work that was performed to support the change.
2-4	TSPA-LA Model Implementation Checklist	Documents the answers to parameter check questions. Conceptual checking and Configuration Management check.
NA	GoldSim Version Report (Run Log)	Provides record of specific changes made to the GoldSim model file (generated by GoldSim).
2-5	TSPA-LA Model Concept Checklist	Documents the answers to concept check questions.

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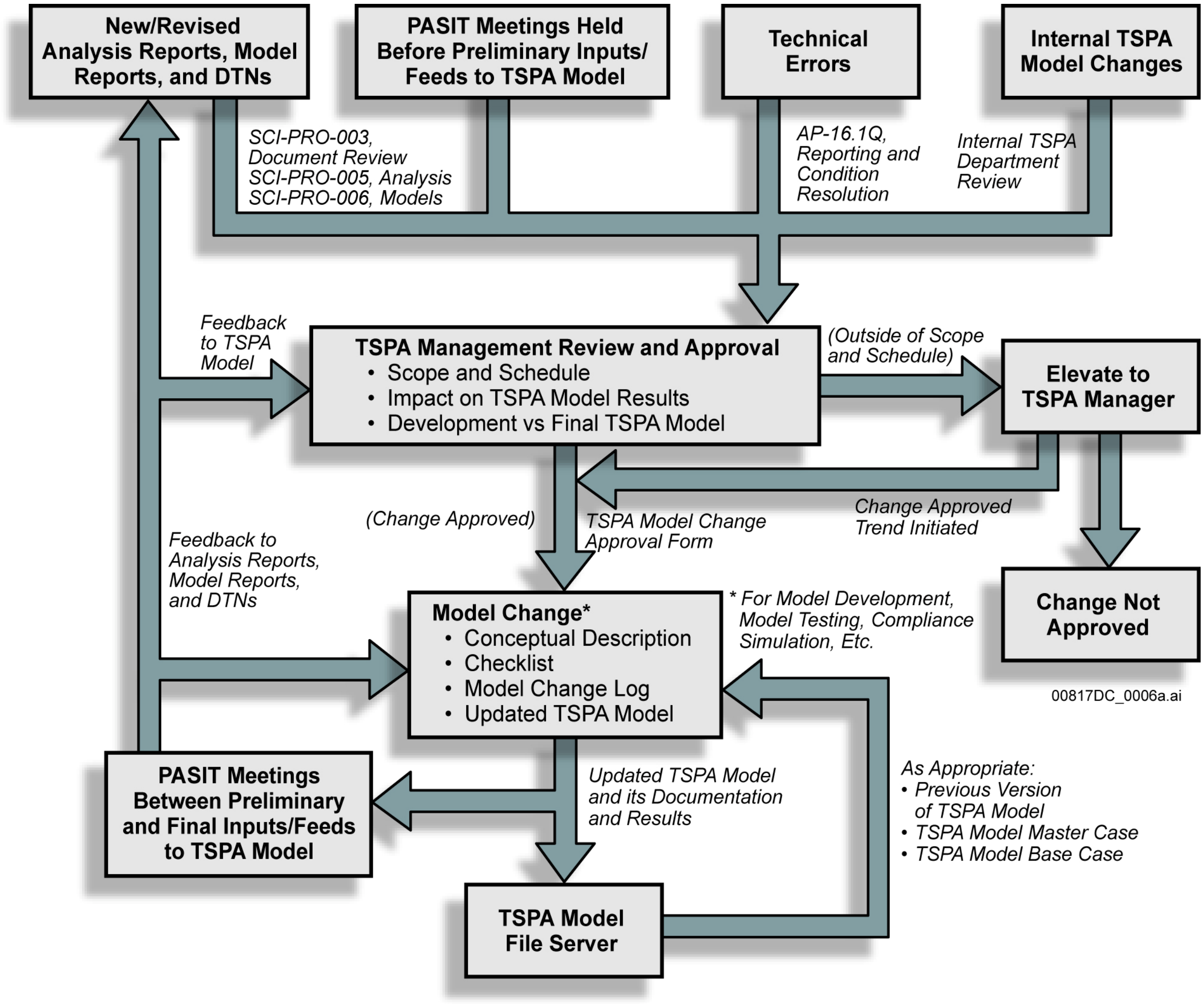
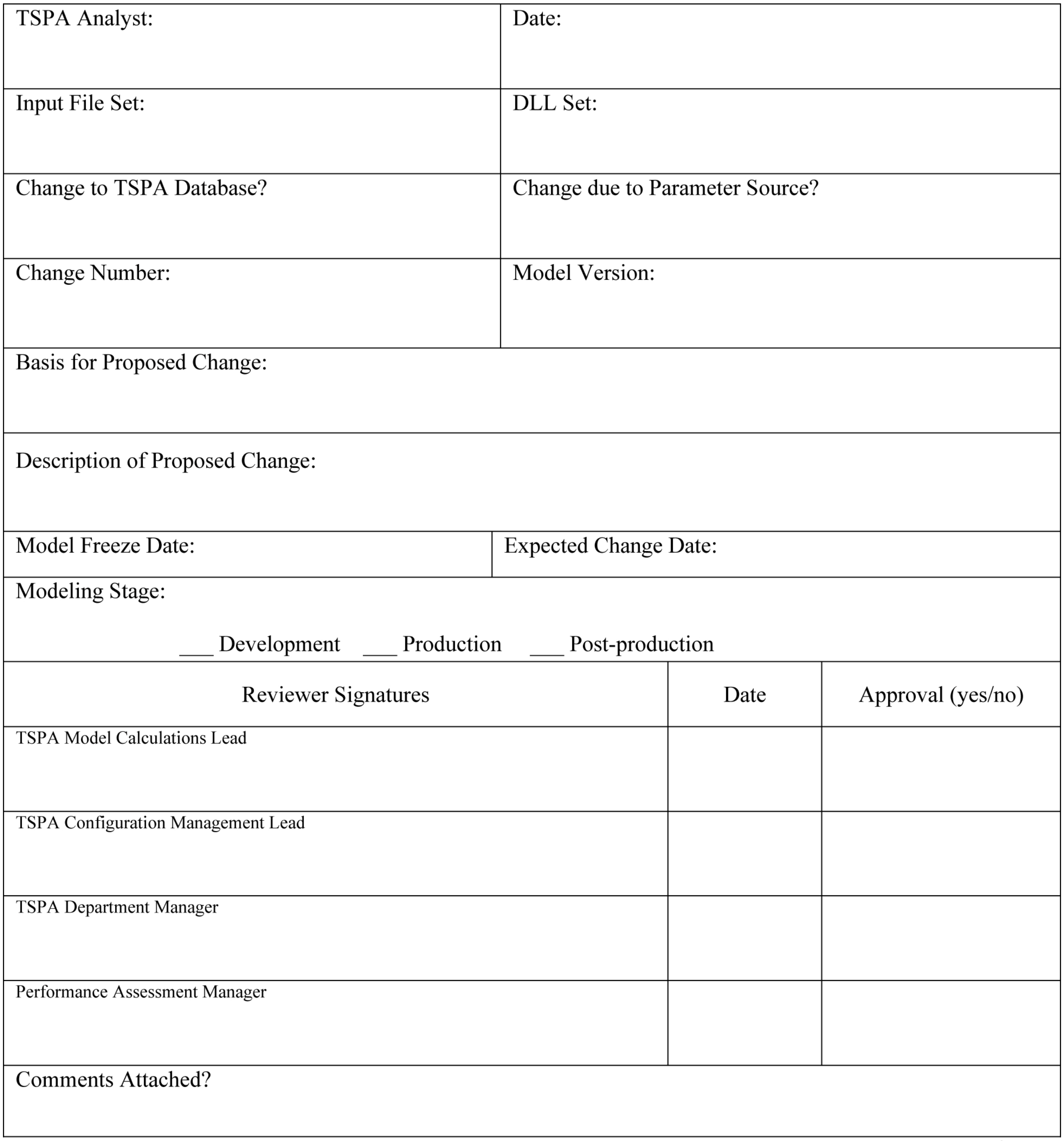


Figure 2-1. Flowchart Illustrating the Management Control Process for the TSPA-LA Model



TSPA Analyst:	Date:
Input File Set:	DLL Set:
Change to TSPA Database?	Change due to Parameter Source?
Change Number:	Model Version:
Basis for Proposed Change:	
Description of Proposed Change:	
Model Freeze Date:	Expected Change Date:

Modeling Stage:

___ Development ___ Production ___ Post-production

Reviewer Signatures	Date	Approval (yes/no)
TSPA Model Calculations Lead		
TSPA Configuration Management Lead		
TSPA Department Manager		
Performance Assessment Manager		

Comments Attached?

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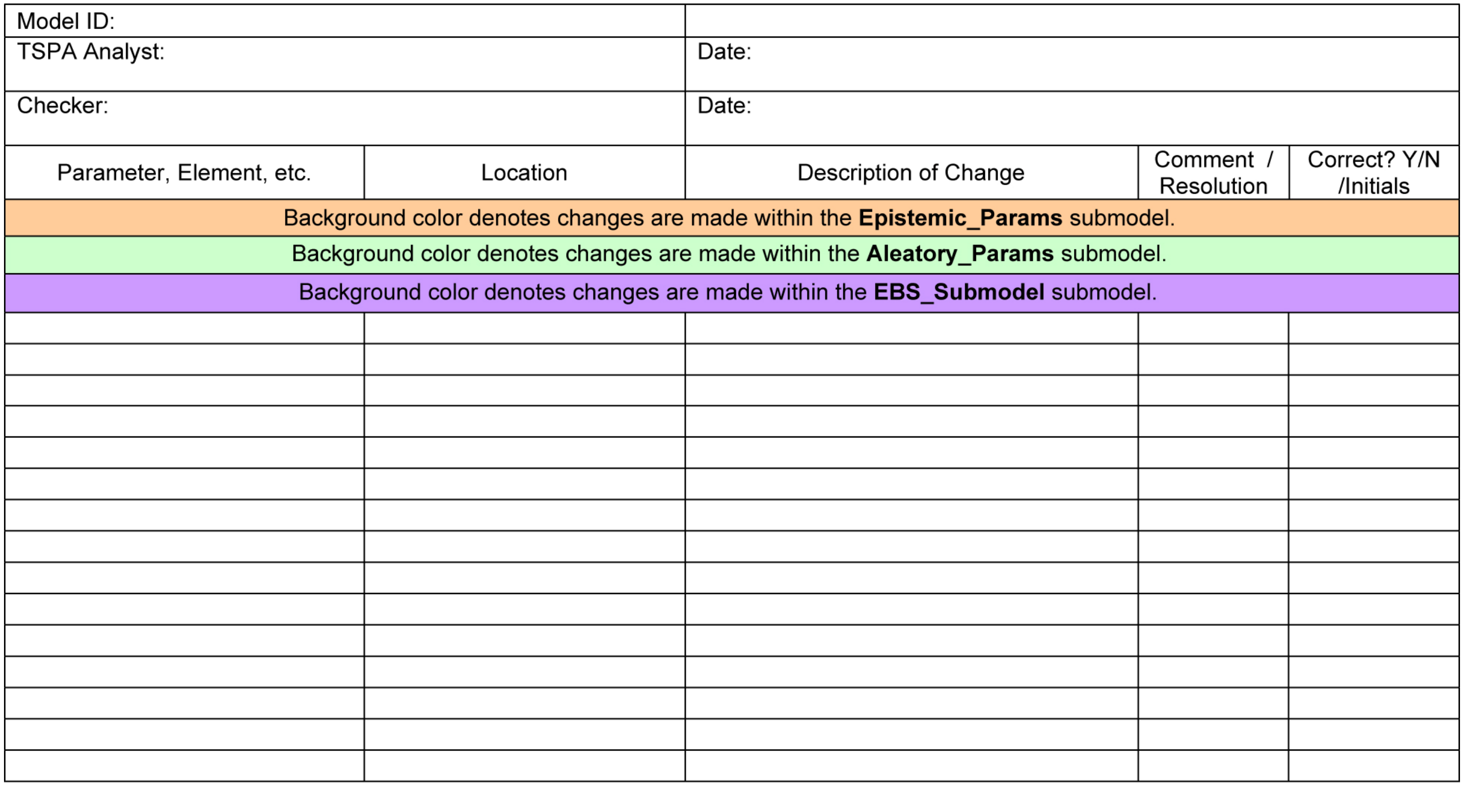
Figure 2-2. Example of the TSPA-LA Model Change Approval Form



Model ID:				
TSPA Analyst:		Date:		
Checker:		Date:		
Parameter, Element, etc.	Location	Description of Change	Comment / Resolution	Correct? Y/N /Initials
🟧 Background color denotes changes are made within the **Epistemic_Params** submodel.				
🟩 Background color denotes changes are made within the **Aleatory_Params** submodel.				
🟪 Background color denotes changes are made within the **EBS_Submodel** submodel.				

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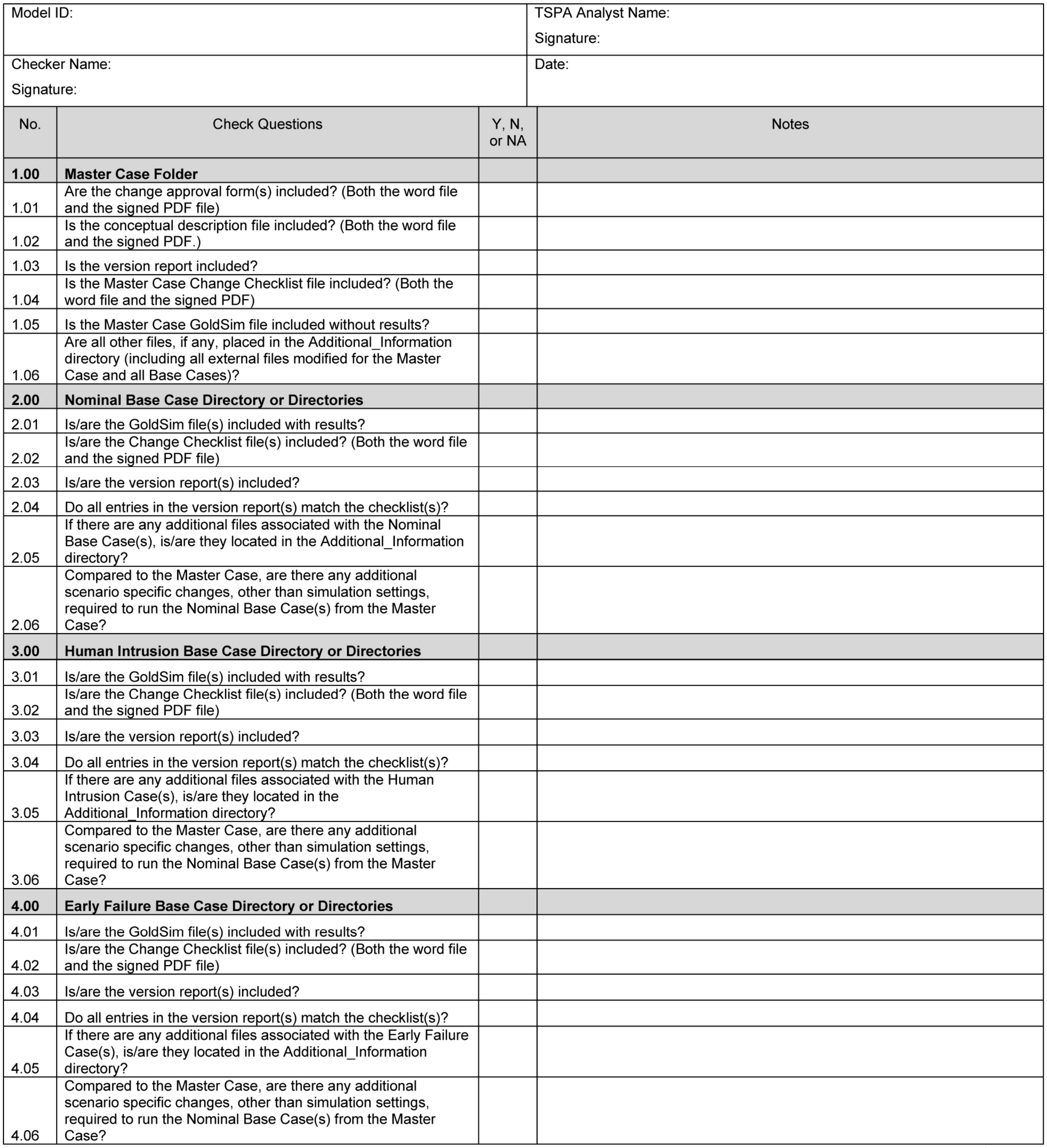
Figure 2-3. Example of the TSPA-LA Model Change Checklist



Model ID:	TSPA Analyst Name: Signature:
Checker Name: Signature:	Date:

No.	Check Questions	Y, N, or NA	Notes
1.00	**Master Case Folder**		
1.01	Are the change approval form(s) included? (Both the word file and the signed PDF file)		
1.02	Is the conceptual description file included? (Both the word file and the signed PDF.)		
1.03	Is the version report included?		
1.04	Is the Master Case Change Checklist file included? (Both the word file and the signed PDF)		
1.05	Is the Master Case GoldSim file included without results?		
1.06	Are all other files, if any, placed in the Additional_Information directory (including all external files modified for the Master Case and all Base Cases)?		
2.00	**Nominal Base Case Directory or Directories**		
2.01	Is/are the GoldSim file(s) included with results?		
2.02	Is/are the Change Checklist file(s) included? (Both the word file and the signed PDF file)		
2.03	Is/are the version report(s) included?		
2.04	Do all entries in the version report(s) match the checklist(s)?		
2.05	If there are any additional files associated with the Nominal Base Case(s), is/are they located in the Additional_Information directory?		
2.06	Compared to the Master Case, are there any additional scenario specific changes, other than simulation settings, required to run the Nominal Base Case(s) from the Master Case?		
3.00	**Human Intrusion Base Case Directory or Directories**		
3.01	Is/are the GoldSim file(s) included with results?		
3.02	Is/are the Change Checklist file(s) included? (Both the word file and the signed PDF file)		
3.03	Is/are the version report(s) included?		
3.04	Do all entries in the version report(s) match the checklist(s)?		
3.05	If there are any additional files associated with the Human Intrusion Case(s), is/are they located in the Additional_Information directory?		
3.06	Compared to the Master Case, are there any additional scenario specific changes, other than simulation settings, required to run the Nominal Base Case(s) from the Master Case?		
4.00	**Early Failure Base Case Directory or Directories**		
4.01	Is/are the GoldSim file(s) included with results?		
4.02	Is/are the Change Checklist file(s) included? (Both the word file and the signed PDF file)		
4.03	Is/are the version report(s) included?		
4.04	Do all entries in the version report(s) match the checklist(s)?		
4.05	If there are any additional files associated with the Early Failure Case(s), is/are they located in the Additional_Information directory?		
4.06	Compared to the Master Case, are there any additional scenario specific changes, other than simulation settings, required to run the Nominal Base Case(s) from the Master Case?		

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Figure 2-4. Example of the TSPA-LA Model Implementation Checklist

Model ID:	TSPA Analyst Name: Signature:
Checker Name: Signature:	Date:

No.	Check Questions	Y, N, or NA	Notes
5.00	**Igneous Base Case Directory or Directories**		
5.01	Is/are the GoldSim file(s) included with results?		
5.02	Is/are the Change Checklist file(s) included? (Both the word file and the signed PDF file)		
5.03	Is/are the version report(s) included?		
5.04	Do all entries in the version report(s) match the checklist(s)?		
5.05	If there are any additional files associated with the Igneous Base Case, are they located in the Additional_Information directory?		
5.06	Compared to the Master Case, are there any additional scenario specific changes, other than simulation settings, required to run the Igneous Base Case(s) from the Master Case?		
6.00	**Seismic Base Case Directories**		
6.01	Is/are the GoldSim file(s) included with results?		
6.02	Is/are the Change Checklist file(s) included? (Both the word file and the signed PDF file)		
6.03	Is/are the version report(s) included?		
6.04	Do all entries in the version report(s) match the checklist(s)?		
6.05	If there are any additional files associated with the Seismic Base Case(s), are they located in the Additional_Information directory?		
6.06	Compared to the Master Case, are there any additional scenario specific changes, other than simulation settings, required to run the Seismic Base Case(s) from the Master Case?		
7.00	**Change Control Check**		
7.01	Does/Do the Change Approval Form(s) need to be revised to address additional scope discovered during version change?		
7.02	Does the Master Case originate from the previous Master Case?		
7.03	Are all input file transfers controlled by the Input Database and associated file elements?		
7.04	Are all DLL file transfers controlled by the Input Database and associated file elements?		
7.05	Was the Master Case versioned before the Base Cases were run?		
7.06	Was a database download performed before running the Base Cases?		
7.07	If this Master Case requires changes to an external file, are copies of the modified files placed in the Additional_Information directory for the Master Case?		
7.08	Is the Master Case checklist consistent with the Master Case Goldsim version report?		
7.09	Are all changes associated with input changes and conceptual model changes documented with sufficient source information in the checklist? (i.e. TMRB proposal #, DTN change, error log entry, new AMR etc.)		
7.10	Are the Base Case checklists consistent with the Base Case Goldsim version reports?		

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Figure 2-4. Example of the TSPA-LA Model Implementation Checklist (Continued)

Model ID:	TSPA Analyst Name: Signature:
Checker Name: Signature:	Date:

No.	Check Questions	Y, N, or NA	Notes
8.00	**Element Level Check**		
8.01	Are all new inputs, if any, added to the Input Database? Are new input elements connected to the Input Database?		
8.02	Have all changed/added Goldsim elements been checked against their source information to verify that they were changed correctly?		
8.03	If a cloned element was changed, was the changed element and at least one of its clones checked to be identical?		
8.04	Are the input links of added elements correct?		
8.05	Are the output links of added parameters correct?		
8.06	Are the links to and from any deleted elements appropriately reconnected?		
8.07	Are all changes to external files correct?		
9.00	**Conceptual Level Check**		
9.01	Is the conceptual description consistent with the change approval form?		
9.02	Is the Master Case Change Checklist consistent with the conceptual description?		
9.03	Are all conceptual model changes made in the Master Case?		
9.04	Is mass conserved within each major subsystem?		
9.05	Can each entry in the GoldSim run log be shown to have no/negligible impact on the run?		
10.00	**Error Tracking**		
10.01	Are there any model errors in this case that will be addressed in a future version of the model?		
10.02	Are errors noted by 10.01 adequately described in the error log, including a proposed correction?		
10.03	Are there any previously logged model errors addressed in this case?		
10.04	If errors noted by 10.03 are addressed in this case, is their treatment adequately documented in this case's conceptual description and Master Case checklist.		
10.05	If errors noted by 10.03 are addressed in this case, has the error log entry been updated to reflect that the correction has been made?		

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Figure 2-4. Example of the TSPA-LA Model Checking Implementation Checklist (Continued)

Concept Analyst Checklist for TSPA Model Version:

Analyst (name):

Analyst (sig): Date:

Checker (name):

Checker (sig): Date:

1.00	**Conceptual Level Check**	**Y,N, or n/a**	**Notes**
1.01	Is the objective adequately and clearly stated?		
	Are the conceptual descriptions sufficiently detailed to:		
1.02	Understand it's purpose?		
1.03	Explain what is intended to be done?		
1.04	Explain how it is intended to be done?		
1.05	Explain why it is being done?		
1.06	Properly designed for each relevant scenario?		
1.07	Does the implementation address the conceptual design in detail and intent for each scenario?		
1.08	Does the conceptual design, it's implementation, and analysis of results accomplish the stated purpose?		
1.09	Does the modified portion of the model respond appropriately to its inputs?		
1.10	Do the model components downstream from the modifications respond appropriately?		
1.11	Are model inputs and outputs within their specified ranges?		
1.12	Can the final dose results be explained in terms of upstream parameters (e.g., waste package/drip shield failure curves, seepage flow, pH, solubilities, EBS release rates)?		
1.13	Did the modification(s) invalidate or bring into question assumptions of an upstream or downstream conceptual model?		
1.14	Is the model implemented correctly for all scenario classes?		
1.15	Are there any unintended behaviors that cannot be explained?		
1.16	Is there additional work needed or outstanding issues generated as a result of this work?		

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Figure 2-5. Example of the TSPA-LA Model Concept Checklist

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3. USE OF SOFTWARE

A number of software codes were implemented to support the development of the TSPA-LA Model. Some of the software codes were used to provide supporting information and some were directly implemented in the TSPA-LA Model using the GoldSim simulation software code. Supporting software codes, including process models, were developed and operated externally before running the TSPA-LA Model. Software codes directly implemented in the TSPA-LA Model are generally referred to as abstractions and are run within the TSPA-LA Model. All software codes used to support the TSPA-LA Model are qualified and have been placed under the control of SCM per IM-PRO-003, *Software Management*. Each qualified software code is in SCM and uniquely identified with a tracking number. The SCM database also includes information on the software name, version, hardware platform, and operating system under which the software code was qualified. All software documentation, including the software media, is linked to this tracking number.

The software codes used to support the TSPA-LA Model are listed in Table 3-1 along with their unique STNs. A few of the software codes (e.g., GoldSim, SEEPAGE, and FEHM) are identified here in Section 3 with several versions, because they were used for the development and prototyping of the TSPA-LA Model. The software codes used in the TSPA-LA Model that are validated in Section 7 and used to develop the results and conclusions presented in Section 8 are identified in Table 3-1 and individually discussed in Section 6. Brief descriptions of the primary function(s) of the software codes are also provided in Sections 3.1 through 3.22. The software codes used to support the TSPA-LA Model were selected because they were either developed specifically for use with the TSPA-LA Model or considered to be the most suitable software codes on the Yucca Mountain Project Software Baseline. As a result, there are no limitations on the outputs of any of the software codes used to support the TSPA-LA Model. All software codes used for the TSPA-LA were qualified in accordance with the procedures that were in place at the time of their qualification.

Qualification documentation for each software code is available in SCM as well as the Records Processing Center. All software codes were obtained from SCM, were appropriate for use in this analysis, and each was used within the software's range of validation. Unless noted otherwise, the software codes described below are directly linked to the GoldSim software code used during the TSPA-LA analyses.

Installation of Qualified TSPA-LA Software Codes on TSPA-LA Department Computers—The installation process for each software code listed in this section was followed to ensure that there was a proper, qualified (i.e., in accordance with governing project procedures and controlled by SCM) installation by personnel authorized by SCM. Because installation procedures have changed during the course of developing the TSPA-LA Model, the installation process is described in one of the following types of documents: Installation Test Process, Software Management Report, or User Information Document.

In order to run the TSPA-LA Model, two types of installations were performed: the GoldSim installation and supporting DLL installations. The installations for GoldSim and callable DLL software routines have the following similarities: (1) both types of installations are qualified, (2) both document the installations using a procedurally required form called a Software User

Request, and (3) both collect the objective evidence of the installation and forward it to SCM. SCM then submits the installation documentation to the Records Processing Center.

One key difference between GoldSim and the callable DLLs is that GoldSim is installed on all master computers, remote processors, and local (desktop) computers, whereas DLLs are only installed on a single computer identified as the PA_Cronus. The PA_Cronus is a TSPA-LA computer that serves as a file server to all the other computers in the TSPA-LA Department. The single installation of the DLLs on the PA_Cronus is possible because of the nature of the GoldSim qualification.

When GoldSim was qualified, the qualification process verified and tested that the DLLs, input files, and database parameters were obtained from the PA_Cronus file server and properly distributed to remote processors as part of the GoldSim distributed processing environment.

In summary, the TSPA-LA Model was run on TSPA-LA Department distributed processing network computers using qualified installations of GoldSim and the DLLs.

TSPA-LA Model Computing Environment—The computer system utilized for the TSPA-LA Model is based on a TSPA-wulf personal computer cluster consisting of more than 752 processors (Figure 3-1) with 6 to 16 GB of RAM available to each processor (note that TSPA-wulf is a TSPA-LA phrase that refers to building a supercomputer by interconnecting a cluster of off-the-shelf personal computers). Realizations are fed from a central server to the processors to accomplish the distributed processing. When this report was prepared, run time for the TSPA-LA Model was approximately two hours for each realization.

This system has evolved and become more powerful with each successive iteration of the TSPA-LA. The numbers of processors utilized, processor speed, and physical memory have increased by an order of magnitude. This allows the TSPA-LA Model to incorporate more detail and provide rapid turnaround as analyses are developed. The architecture of the computing environment is shown on Figure 3-2. The system has 30 master servers for distributing jobs or analyses. A large file server contains storage for input and output files and the TSPA-LA Input Database. The system has a backup power supply and is capable of remote access, if necessary.

3.1 INTRODUCTION

The sections that follow identify the following types of information: (1) name of software; (2) brief description of software; (3) relationship to the TSPA-LA Model (i.e., used for model development only, model development and final model, or final model only); (4) location of software documentation; and (5) statement regarding use of code within range of validation. The sections are listed in alphabetical order. The tables that contain the software documents are numbered to match the section number in which they are described.

3.2 ASHPLUME_DLL_LA

3.2.1 Description of Software

All versions of ASHPLUME_DLL_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Calculate the waste and ash areal depositional densities on the ground surface from a hypothetical volcanic eruption through the repository (Section 6.5.2)
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.2.2 Relationship to the TSPA-LA Model

ASHPLUME_DLL_LA V2.0 (STN: 11117-2.0-00 [DIRS 181034]) was used for the TSPA-LA Model development.

ASHPLUME_DLL_LA V2.1 (STN: 11117-2.1-00 [DIRS 181035]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

ASHPLUME_DLL_LA V2.1 (STN: 11117-2.1-01 [DIRS 180147]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.2.3 Software Documentation

The software documents for the versions of ASHPLUME_DLL_LA mentioned in Section 3.2.2 are listed in Table 3-2.

3.2.4 Range of Validation

The range of validation for the versions of ASHPLUME_DLL_LA listed in Section 3.2.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-2. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-2.

3.3 CWD

3.3.1 Description of Software

All versions of CWD used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Implement the abstraction results of the probability of occurrence and size of manufacturing defects in the closure lid welds of the Alloy 22 WP outer surface
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.3.2 Relationship to the TSPA-LA Model

CWD V2.0 (STN: 10363-2.0-00 [DIRS 162809]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases. CWD V2.0 (STN: 10363-2.0-01 [DIRS 181037]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.3.3 Software Documentation

The software documents for the versions of CWD mentioned in Section 3.3.2 are listed in Table 3-3.

3.3.4 Range of Validation

The range of validation for the versions of CWD listed in Section 3.3.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report listed in Table 3-3. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-3.

3.4 EXDOC_LA

3.4.1 Description of Software

EXDOC_LA V2.0 (STN: 11193-2.0-00 [DIRS 182102]) calculates the expected annual dose, as well as, statistics for expected annual dose (i.e., mean and quantiles) for each modeling case.

3.4.2 Relationship to the TSPA-LA Model

EXDOC_LA V2.0 was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases. A controlled version of EXDOC_LA V2.0 was used prior to a qualified version.

3.4.3 Software Documentation

The software documents for the version of EXDOC_LA V2.0 mentioned in Section 3.4.2 are listed in Table 3-4.

3.4.4 Range of Validation

The range of validation for the version of EXDOC_LA listed in Section 3.4.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the requirements document listed in Table 3-4. The range(s) of acceptable inputs is discussed in the design and user documents listed in Table 3-4.

3.5 FAR

3.5.1 Description of Software

All versions of FAR used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Implement the Fortymile Wash volcanic ash redistribution (Section 6.5.2) into the TSPA-LA Model
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.5.2 Relationship to the TSPA-LA Model

FAR V1.1 (STN: 11190-1.1-00 [DIRS 180002]) was used for the TSPA-LA Model development. FAR V1.2 (STN: 11190-1.2-00 [DIRS 182225]) was used for the TSPA-LA Model validation and analysis cases.

A controlled version of FAR V1.2 was used prior to a qualified version. After qualification, FAR V1.2 was obtained from SCM in accordance with the governing procedure (IM-PRO-003) and installed. The FAR V1.2 installation package documents the confirmation that the controlled version of FAR V1.2 is identical to the qualified version of FAR V1.2 obtained from SCM.

3.5.3 Software Documentation

The software documents for the versions of FAR mentioned in Section 3.5.2 are listed in Table 3-5.

3.5.4 Range of Validation

The range of validation for the versions of FAR listed in Section 3.5.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-5. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-5.

3.6 FEHM

3.6.1 Description of Software

All versions of FEHM used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in the *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Calculate the transport of radionuclides through the UZ
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.6.2 Relationship to the TSPA-LA Model

FEHM V2.23 (STN: 10086-2.23-00 [DIRS 173139]) was used for the TSPA-LA Model development.

FEHM V2.24-01 (STN: 10086-2.24-01-00 [DIRS 179419]) was used for the TSPA-LA Model validation and analysis cases.

3.6.3 Software Documentation

The software documents for the versions of FEHM mentioned in Section 3.6.2 are listed in Table 3-6.

3.6.4 Range of Validation

The range of validation for the versions of FEHM listed in Section 3.6.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-6. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-6.

3.7 GETTHK_LA

3.7.1 Description of Software

GetThk_LA V1.0 (STN: 11229-1.0-00 [DIRS 181040]) has the following general capabilities:

- Is called from another program that conforms to the external interface method and function calls described in the *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provides GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Reads WAPDEG output for the Seismic Scenario Class and calculates statistics (Section 6.6)
- Transfers information back and forth to the GoldSim software running the TSPA-LA Model.

3.7.2 Relationship to the TSPA-LA Model

GetThk_LA V1.0 was used for the TSPA-LA Model validation and analysis cases.

3.7.3 Software Documentation

The software documents for the version of GetThk_LA V1.0 mentioned in Section 3.7.2 are listed in Table 3-7.

3.7.4 Range of Validation

The range of validation for the version of GetThk_LA listed in Section 3.7.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-7. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-7.

3.8 GOLDSIM

3.8.1 Description of Software

All versions of GoldSim used in the TSPA-LA Model documented in this report have the following general capabilities:

- Address the inherent variability and uncertainty that is present in real-world systems by using Monte Carlo simulation
- Superimpose the occurrence and consequences of discrete events onto continuously varying systems
- Build top-down models using hierarchical containers that facilitate the simulation of large, complex systems that are easy to understand and navigate
- Dynamically link external programs or spreadsheets directly to the GoldSim software
- Directly exchange information between any Open Database Connectivity (ODBC)-compliant (Yucca Mountain Structured) database and GoldSim.

3.8.2 Relationship to the TSPA-LA Model

GoldSim V9.60. (STN: 10344-9.60-00 [DIRS 180224]) was used for the TSPA-LA Model development.

GoldSim V9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

A controlled version of GoldSim V9.60.100 was used prior to a qualified version. After qualification, GoldSim V9.60.100 was obtained from SCM in accordance with the governing procedure (IM-PRO-003) and installed. The GoldSim V9.60.100 installation package documents the confirmation that the controlled version of GoldSim V9.60.100 is identical to the qualified version of GoldSim V9.60.100 obtained from SCM.

3.8.3 Software Documentation

The software documents for the versions of GoldSim mentioned in Section 3.8.2 are listed in Table 3-8.

3.8.4 Range of Validation

The range of validation for the versions of GoldSim listed in Section 3.8.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-8. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-8.

3.9 INTERPZDLL_LA

3.9.1 Description of Software

All versions of InterpZdll_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim the ability to perform calculations not included in the standard capabilities of GoldSim
- Provide interpolation capabilities for the EBS Chemical Environment Submodel of the TSPA-LA Model (Section 6.3.4)
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.9.2 Relationship to the TSPA-LA Model

InterpZdll_LA V1.0 (STN: 11107-1.0-00 [DIRS 167885]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

InterpZdll_LA V1.0 (STN: 11107-1.0-01 [DIRS 181043]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.9.3 Software Documentation

The software documents for the versions of InterpZdll_LA mentioned in Section 3.9.2 are listed in Table 3-9.

3.9.4 Range of Validation

The range of validation for the versions of InterpZdll_LA listed in Section 3.9.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report listed in Table 3-9. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-9.

3.10 MFCP_LA

3.10.1 Description of Software

All versions of MFCP_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Control the selection of input files for various DLLs that are part of the TSPA-LA Model
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.10.2 Relationship to the TSPA-LA Model

MFCP_LA V1.0 (STN: 11071-1.0-00 [DIRS 167884]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

MFCP_LA V1.0 (STN: 11071-1.0-01 [DIRS 181045]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.10.3 Software Documentation

The software documents for the versions of MFCP_LA mentioned in Section 3.10.2 are listed in Table 3-10.

3.10.4 Range of Validation

The range of validation for the versions of MFCP_LA listed in Section 3.10.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report listed in Table 3-10. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-10.

3.11 MKTABLE AND MKTABLE_LA

3.11.1 Description of Software

All versions of MkTable and MkTable_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Control the selection of input files for various DLLs that are part of the TSPA-LA Model
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.11.2 Relationship to the TSPA-LA Model

MkTable V1.00 (STN: 10505-1.00-00 [DIRS 174528]) was used for the TSPA-LA Model development.

MkTable_LA V1.0 (STN: 11217-1.0-00 [DIRS 181047]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

MkTable_LA V1.0 (STN: 11217-1.0-01 [DIRS 181048]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.11.3 Software Documentation

The software documents for the versions of MkTable_LA mentioned in Section 3.11.2 are listed in Table 3-11.

3.11.4 Range of Validation

The range of validation for the versions of MkTable_LA listed in Section 3.11.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report and the respective requirements documents listed in Table 3-11. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-11.

3.12 MVIEW

3.12.1 Description of Software

MVIEW V4.0 (STN: 10072-4.0-01 [DIRS 181049]) is a stand-alone executable program that transforms text output describing numeric model geometry and numeric model output into two-dimensional and three-dimensional visual representations.

3.12.2 Relationship to the TSPA-LA Model

MVIEW V4.0 is not part of the TSPA-LA Model. Rather, MVIEW is used to interpret the results of the TSPA-LA Model using two-dimensional and three-dimensional visual representations. MVIEW V4.0 is also used to statistically analyze the TSPA-LA Model output.

3.12.3 Software Documentation

The software documents for the version of MVIEW 4.0 mentioned in Section 3.12.2 are listed in Table 3-12.

3.12.4 Range of Validation

The range of validation for the version of MVIEW listed in Section 3.12.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the requirements document listed in Table 3-12. The range(s) of acceptable inputs is discussed in the design and user documents listed in Table 3-12.

3.13 PASSTABLE1D_LA

3.13.1 Description of Software

All versions of PassTable1D_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Read one-dimensional tabular information from an input file and pass that information into GoldSim in a format that is compatible with the external definition of a one-dimensional look-up table element
- Support the evaluation of localized corrosion on the WPs.

3.13.2 Relationship to the TSPA-LA Model

PassTable1D_LA V1.0 (STN: 11142-1.0-00 [DIRS 169130]) was used for the TSPA-LA Model development.

PassTable1D_LA V1.0 (STN: 11142-1.0-01 [DIRS 181050]) was used for the TSPA-LA Model development.

PassTable1D_LA V2.0 (STN: 11142-2.0-00 [DIRS 181051] was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.13.3 Software Documentation

The software documents for the versions of PassTable1D_LA mentioned in Section 3.13.2 are listed in Table 3-13.

3.13.4 Range of Validation

The range of validation for the versions of PassTable1D_LA listed in Section 3.13.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report and respective requirements documents listed in Table 3-13. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-13.

3.14 PASSTABLE3D_LA

3.14.1 Description of Software

All versions of PassTable3D_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Read three-dimensional tabular information from an input file and pass that information into GoldSim in a format that is compatible with the external definition of a three-dimensional look-up table element
- Support the evaluation of localized corrosion on the WPs (Sections 6.3.5).

3.14.2 Relationship to the TSPA-LA Model

PassTable3D_LA V1.0 (STN: 11143-1.0-00 [DIRS 168980]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

PassTable3D_LA V1.0 (STN: 11143-1.0-01 [DIRS 181052]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

PassTable3D_LA V2.0 (STN: 11143-2.0-00 [DIRS 182556]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.14.3 Software Documentation

The software documents for the versions of PassTable3D_LA mentioned in Section 3.14.2 are listed in Table 3-14.

3.14.4 Range of Validation

The range of validation for the versions of PassTable3D_LA listed in Section 3.14.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report and the respective requirements documents listed in Table 3-14. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-14.

3.15 PREWAP_LA

3.15.1 Description of Software

PREWAP_LA V1.1 (STN: 10939-1.1-00 [DIRS 181053]) has the following general capabilities:

- Implements the processing of output files produced by the Multiscale Thermal-Hydrologic Abstraction software, MSTHAC V7.0 (STN: 10419-7.0-00 [DIRS 164274]).
- Processes files from MSTHAC V7.0 as input for DLLs (e.g., WAPDEG) (STN: 10000-4.07-00 [DIRS 181774]), which are components of the TSPA-LA Model.

3.15.2 Relationship to the TSPA-LA Model

PREWAP_LA V1.1 was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.15.3 Software Documentation

The software documents for the version of PREWAP_LA V1.1 mentioned in Section 3.15.2 are listed in Table 3-15.

3.15.4 Range of Validation

The range of validation for the version of PREWAP_LA listed in Section 3.15.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the requirements document listed in Table 3-15. The range(s) of acceptable inputs is discussed in the design and user documents listed in Table 3-15.

3.16 SCCD

3.16.1 Description of Software

All versions of SCCD used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Implement the abstraction results of the stress and stress-intensity factor profiles in the closure-lid welds of the Alloy 22 WP outer surface
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.16.2 Relationship to the TSPA-LA Model

SCCD V2.01 (STN: 10343-2.01-00 [DIRS 181157]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

SCCD V2.01 (STN: 10343-2.01-01 [DIRS 181054]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.16.3 Software Documentation

The software documents for the versions of SCCD mentioned in Section 3.16.2 are listed in Table 3-16.

3.16.4 Range of Validation

The range of validation for the versions of SCCD listed in Section 3.16.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Routine Report listed in Table 3-16. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-16.

3.17 SEEPAGEDLL_LA

3.17.1 Description of Software

All versions of SEEPAGEDLL_LA used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8

- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim

- Implement the Drift Seepage Abstraction (Section 6.3.3.1.2) into the TSPA-LA Model

- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.17.2 Relationship to the TSPA-LA Model

SEEPAGEDLL_LA V1.2 (STN: 11076-1.2-00 [DIRS 173435]) was used for the TSPA-LA Model development.

SEEPAGEDLL_LA V1.3 (STN: 11076-1.3-00 [DIRS 180318]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

SEEPAGEDLL_LA V1.3 (STN: 11076-1.3-01 [DIRS 181058]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.17.3 Software Documentation

The software documents for the versions of SEEPAGEDLL_LA mentioned in Section 3.17.2 are listed in Table 3-17.

3.17.4 Range of Validation

The range of validation for the versions of SEEPAGEDLL_LA listed in Section 3.17.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-17. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-17.

3.18 SOILEXP_LA

3.18.1 Description of Software

SOILEXP_LA V1.0 (STN: 10933-1.0-00 [DIRS 167883]) has the following general capabilities:

- Is called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provides GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Calculates the cumulative redistribution factors used to calculate the radionuclide concentration in volcanic ash after it is deposited
- Transfers information back and forth to the GoldSim software running the TSPA-LA Model.

3.18.2 Relationship to the TSPA-LA Model

SOILEXP_LA V1.0 was used for the TSPA-LA Model development.

3.18.3 Software Documentation

The software document for the version of SoilExp_LA V1.0 mentioned in Section 3.18.2 is listed in Table 3-18.

3.18.4 Range of Validation

The range of validation for the version of SoilExp_LA listed in Section 3.18.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the Software Management Report listed in Table 3-18. The range(s) of acceptable inputs is discussed in the design and user documents listed in Table 3-18.

3.19 SZ_CONVOLUTE

3.19.1 Description of Software

All versions of SZ_Convolute used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8

- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Calculate the radionuclide mass-flux rates in accordance with the three-dimensional SZ Flow and Transport Abstraction (Section 6.3.10)
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.19.2 Relationship to the TSPA-LA Model

SZ_Convolute V3.0 (STN: 10207-3.0-00 [DIRS 164180]) was used for the TSPA-LA Model development.

SZ_Convolute V3.10.01 (STN: 10207-3.10.01-00 [DIRS 181060]) was used for the TSPA-LA Model development and TSPA-LA-LA Model validation and analysis cases.

3.19.3 Software Documentation

The software documents for the versions of SZ_Convolute mentioned in Section 3.19.2 are listed in Table 3-19.

3.19.4 Range of Validation

The range of validation for the versions of SZ_Convolute listed in Section 3.19.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-19. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-19.

3.20 TSPA_INPUT_DB

3.20.1 Description of Software

All versions of TSPA_Input_DB used in the TSPA-LA Model documented in this report are a Microsoft Access database that is used as a quality-controlled storage area for the TSPA-LA Model input parameters. The parameter values are maintained as originally entered (i.e., no manipulations or post-processing of the parameter values are performed). The database is capable of interfacing via ODBC for automated download to the TSPA-LA Model.

3.20.2 Relationship to the TSPA-LA Model

TSPA_Input_DB V2.2 (STN: 10931-2.2-00 [DIRS 181061]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

TSPA_Input_DB V2.2 (STN: 10931-2.2-01 [DIRS 181062]) was used for the TSPA-LA Model validation and analysis cases.

3.20.3 Software Documentation

The software documents for the versions of the TSPA_Input_DB mentioned in Section 3.20.2 are listed in Table 3-20.

3.20.4 Range of Validation

The range of validation for the versions of TSPA_Input_DB listed in Section 3.20.2 is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-20. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-20.

3.21 WAPDEG

3.21.1 Description of Software

All versions of WAPDEG used in the TSPA-LA Model documented in this report have the following general capabilities:

- Are called from another program that conforms to the external interface method and function calls described in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]) listed in Table 3-8
- Provide GoldSim with the ability to perform calculations not included in the standard capabilities of GoldSim
- Implement the general corrosion, SCC, and MIC abstractions used in the TSPA-LA Model
- Calculate DS and WP failure profiles
- Transfer information back and forth to the GoldSim software running the TSPA-LA Model.

3.21.2 Relationship to the TSPA-LA Model

WAPDEG V4.07 (STN: 10000-4.07-00 [DIRS 181774]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

WAPDEG V4.07 (STN: 10000-4.07-01 [DIRS 181064]) was used for the TSPA-LA Model development and TSPA-LA Model validation and analysis cases.

3.21.3 Software Documentation

The software documents for the versions of WAPDEG mentioned in Section 3.21.2 are listed in Table 3-21.

3.21.4 Range of Validation

The range of validation for the versions of WAPDEG listed in Section 3.21.2 are defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-21. The range(s) of acceptable inputs are discussed in the respective design and user documents listed in Table 3-21.

3.22 CORROBORATIVE SOFTWARE USED

Volume III, Appendix L, describes how computer code written in FORTRAN 90 was used to develop a simplified model. The FORTRAN code used for this work scope will be controlled in corroborative DTN: MO0708SIMPLIFI.000 [DIRS 182980].

Table 3-1. TSPA-LA Model Software Codes

Code	Version	Software Tracking Number	Operating System	DIRS Number
ASHPLUME_DLL_LA[a1]	2.0	STN: 11117-2.0-00	Windows 2000	DIRS 181034
ASHPLUME_DLL_LA[a2]	2.1	STN: 11117-2.1-00	Windows 2000	DIRS 181035
ASHPLUME_DLL_LA[a2]	2.1	STN: 11117-2.1-01	Windows 2003	DIRS 180147
CWD[a2]	2.0	STN: 10363-2.0-00	Windows 2000	DIRS 162809
CWD[a2]	2.0	STN: 10363-2.0-01	Windows 2003	DIRS 181037
EXDOC_LA[b1]	2.0	STN: 11193-2.0-00	Windows 2000 Windows 2003 Windows XP	DIRS 182102
FAR [a1]	1.1	STN: 11190-1.1-00	Windows 2000 Windows 2003	DIRS 180002
FAR [a2]	1.2	STN: 11190-1.2-00	Windows 2000 Windows 2003	DIRS 182225
FEHM[a1]	2.23	STN: 10086-2.23-00	Windows 2000	DIRS 173139
FEHM[a2]	2.24-01	STN: 10086-2.24-01-00	Windows 2000 Windows 2003 Windows XP	DIRS 179419
GetThk_LA [a2]	1.0	STN: 11229-1.0-00	Windows 2000 Windows 2003	DIRS 181040
GoldSim[a1]	9.60	STN: 10344-9.60-00	Windows 2000 Windows 2003 Windows XP	DIRS 180224
GoldSim[a2]	9.60.100	STN: 10344-9.60-01	Windows 2000 Windows 2003 Windows XP	DIRS 181903
InterpZdll_LA [a2]	1.0	STN: 11107-1.0-00	Windows 2000	DIRS 167885
InterpZdll_LA [a2]	1.0	STN: 11107-1.0-01	Windows 2003	DIRS 181043
MFCP_LA[a2]	1.0	STN: 11071-1.0-00	Windows 2000	DIRS 167884
MFCP_LA[a2]	1.0	STN: 11071-1.0-01	Windows 2003	DIRS 181045
MkTable[a1]	1.00	STN: 10505-1.00-00	Windows 2000	DIRS 174528
MkTable_LA[a2]	1.0	STN: 11217-1.0-00	Windows 2000	DIRS 181047
MkTable_LA[a2]	1.0	STN: 11217-1.0-01	Windows 2003	DIRS 181048
MView[b1]	4.0	STN: 10072-4.0-01	Windows XP	DIRS 181049
PassTable1D_LA[a1]	1.0	STN: 11142-1.0-00	Windows 2000	DIRS 169130
PassTable1D_LA[a1]	1.0	STN: 11142-1.0-01	Windows 2003	DIRS 181050
PassTable1D_LA[a2]	2.0	STN: 11142-2.0-00	Windows 2000 Windows 2003	DIRS 181051
PassTable3D_LA[a1]	1.0	STN: 11143-1.0-00	Windows 2000	DIRS 168980
PassTable3D_LA[a1]	1.0	STN: 11143-1.0-01	Windows 2003	DIRS 181052

Table 3-1. TSPA-LA Model Software Codes (Continued)

Code	Version	Software Tracking Number	Operating System	DIRS Number
PassTable3D_LA [a2]	2.0	STN: 11143-2.0-00	Windows 2000 Windows 2003	DIRS 182556
PREWAP_LA[b1]	1.1	STN: 10939-1.1-00	Windows 2000	DIRS 181053
SCCD[a2]	2.01	STN: 10343-2.01-00	Windows 2000	DIRS 181157
SCCD[a2]	2.01	STN: 10343-2.01-01	Windows 2003	DIRS 181054
SEEPAGEDLL_LA[a1]	1.2	STN: 11076-1.2-00	Windows 2000	DIRS 173435
SEEPAGEDLL_LA[a2]	1.3	STN: 11076-1.3-00	Windows 2000	DIRS 180318
SEEPAGEDLL_LA[a2]	1.3	STN: 11076-1.3-01	Windows 2003	DIRS 181058
SoilExp_LA [a1]	1.0	STN: 10933-1.0-00	Windows 2000	DIRS 167883
SZ_Convolute[a1]	3.0	STN: 10207-3.0-00	Windows 2000	DIRS 164180
SZ_Convolute[a2]	3.10.01	STN: 10207-3.10.01-00	Windows 2000/ Windows 2003	DIRS 181060
TSPA_Input_DB[a2]	2.2	STN: 10931-2.2-00	Windows 2000	DIRS 181061
TSPA_Input_DB[a2]	2.2	STN: 10931-2.2-01	Windows 2003	DIRS 181062
WAPDEG[a2]	4.07	STN: 10000-4.07-00	Windows 2000	DIRS 181774
WAPDEG[a2]	4.07	STN: 10000-4.07-01	Windows 2003	DIRS 181064

[a1] Codes are used only for the TSPA-LA Model development (See Note Below).

[a2] Codes used in the TSPA-LA Model that are used for the TSPA-LA Model development (See Note Below) and to develop results and conclusions in Section 8.

[b1] Code is a pre- or post-processor that does not require GoldSim to run codes that are used for the TSPA-LA Model development (See Note Below) and to develop results and conclusions in Section 8.

Note: TSPA model development should not be confused with model development as described in SCI-PRO-006. TSPA model development is merely a phrase to represent the draft model versions (i.e., v4.001 to v4.047) that were created before finalizing the model (e.g., v5.000) presented in this document. These draft model versions will be submitted as part of the records package for this document. All software codes used for the results presented in this document are on the software baseline.

Table 3-2. ASHPLUME_DLL_LA Software Documents

Version 2.0 Windows 2000 (STN: 11117-2.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11117-RD-2.0-00	DIRS 167601	MOL.20031212.0438
Design Document (DD)	11117-DD-2.0-00	DIRS 167603	MOL.20031212.0439
User Manual (UM)	11117-UM-2.0-00	DIRS 167607	MOL.20031212.0444
Installation Test Process (ITP)	11117-ITP-2.0-00	DIRS 167606	MOL.20031212.0440
Validation Test Process (VTP)	11117-VTP-2.0-01	DIRS 167604	MOL.20031212.0441
Validation Test Report (VTR)	11117-VTR-2.0-00	DIRS 166506	MOL.20031212.0443
Version 2.1 Windows 2000 (STN: 11117-2.1-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11117-RD-2.1-00	DIRS 181073	MOL.20061106.0385
Design Document (DD)	11117-DD-2.1-00	DIRS 181075	MOL.20061106.0387
User Information Document (UID)	11117-UID-2.1-00	DIRS 181076	MOL.20070102.0242
Software Validation Report (SVR)	11117-SVR-2.1-00-WIN2000	DIRS 181077	MOL.20070102.0246
Version 2.1 Windows 2003 (STN: 11117-2.1-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	Same as above	NA	NA
Design Document (DD)	Same as above	NA	NA
User Information Document (UID)	Same as above	NA	NA
Software Validation Report (SVR)	11117-SVR-2.1-01-WIN2003	DIRS 181275	MOL.20070223.0261

Table 3-3. CWD Software Documents

Version 2.0 Windows 2000 (STN: 10363-2.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	10363-SMR-2.0-00	DIRS 167564	MOL.20030501.0182
Version 2.0 Windows 2003 (STN: 10363-2.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	Same as above	NA	NA
Software Validation Report (SVR)	10363-SVR-2.0-01-WIN2003	DIRS 181079	MOL.20070209.0021

Table 3-4. EXDOC_LA Software Documents

Version 2.0 Windows 2000 (STN: 11193-2.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11193-RD-2.0-01	DIRS 182906	MOL.20070723.0260
Design Document (DD)	11193-DD-2.0-01	DIRS 182907	MOL.20070723.0262
User Information Document (UID)	11193-UID-2.0-00	DIRS 182908	MOL.20070723.0264
Software Validation Report (SVR)	11193-SVR-2.0-00-WIN2000	DIRS 182909	MOL.20070723.0266
Software Validation Report (SVR)	11193-SVR-2.0-00-WIN2003	DIRS 182910	MOL.20070723.0268
Software Validation Report (SVR)	11193-SVR-2.0-00-WINXP	DIRS 182911	MOL.20070723.0270

Table 3-5. FAR Software Documents

Version 1.1 Windows 2000 and Windows 2003 (STN:11190-1.1-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11190-RD-1.1-00	DIRS 181080	MOL.20070323.0326
Design Document (DD)	11190-DD-1.1-00	DIRS 181081	MOL.20070323.0328
User Information Document (UID)	11190-UID-1.1-00	DIRS 181084	MOL.20070417.0336
Software Validation Report (SVR)	11190-SVR-1.1-00-WIN2000	DIRS 181085	MOL.20070417.0338
Software Validation Report (SVR)	11190-SVR-1.1-00-WIN2003	DIRS 181087	MOL.20070417.0340
Version 1.2 Windows 2000 AND 2003 (STN: 11190-1.2-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11190-RD-1.2-00	DIRS 183117	MOL.20070919.0325.
Design Document (DD)	11190-DD-1.2-00	DIRS 183118	MOL.20070919.0327
User Information Document (UID)	11190-UID-1.2-00	DIRS 183116	MOL.20070919.0332
Software Validation Report (SVR)	11190-SVR-1.2-00-WIN2000	DIRS 183120	MOL.20070919.0334
Software Validation Report (SVR)	11190-SVR-1.2-00-WIN2003	DIRS 183121	MOL.20070919.0336

Table 3-6. FEHM Software Documents

Version 2.23 Windows 2000 (STN: 10086-2.23-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10086-RD-2.23-00	DIRS 174616	MOL.20050301.0040
Design Document (DD)	10086-DD-2.23-00	DIRS 173440	MOL.20050301.0043
User Information Document (UID)	10086-UID-2.23-00	DIRS 173441	MOL.20050301.0046
Software Validation Report (SVR)	10086-SVR-2.23-00-WIN2000	DIRS 173442	MOL.20050301.0049
Version 2.24-01 Windows 2000 and 2003 (STN: 10086-2.24-01-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10086-RD-2.24-00	DIRS 181094	MOL.20061127.0272
Design Document (DD)	10086-DD-2.24-01-00	DIRS 181095	MOL.20070309.0032
User Information Document (UID)	10086-UID-2.24-01-00	DIRS 181096	MOL.20070309.0037
Software Validation Report (SVR)	10086-SVR-2.24-01-00-WIN2000	DIRS 181097	MOL.20070309.0047
Software Validation Report (SVR)	10086-SVR-2.24-01-00-WIN2003	DIRS 181098	MOL.20070309.0045

Table 3-7. GetThk_LA Software Documents

Version 1.0 Windows 2000 and 2003 (STN: 11229-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11229-RD-1.0-00	DIRS 181100	MOL.20060915.0163
Design Document (DD)	11229-DD-1.0-00	DIRS 181101	MOL.20060915.0165
User Information Document (UID)	11229-UID-1.0-00	DIRS 181102	MOL.20060915.0169
Software Validation Report (SVR)	11229-SVR-1.0-00-WIN2000	DIRS 181104	MOL.20060915.0173
Software Validation Report (SVR)	11229-SVR-1.0-00-WIN2003	DIRS 181105	MOL.20060915.0171

Table 3-8. GoldSim Software Documents

Version 9.60 Windows 2000, Windows 2003, and Windows XP (STN: 10344-9.60-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10344-RD-9.60-00	DIRS 181106	MOL.20070416.0330
Design Document (DD)	10344-DD-9.60-01	DIRS 181107	MOL.20070416.0338
User Information Document (UID)	10344-UID-9.60-00	DIRS 181108	MOL.20070416.0339
User's Guide, GoldSim Probabilistic Simulation Environment, V. 9.60	NA	DIRS 181727	TIC: 259221
Software Validation Report (SVR)	10344-SVR-9.60-00-WIN2000	DIRS 181109	MOL.20070416.0341
Software Validation Report (SVR)	10344-SVR-9.60-00-WIN2003	DIRS 181110	MOL.20070416.0343
Software Validation Report (SVR)	10344-SVR-9.60-00-WINXP	DIRS 181111	MOL.20070416.0345
Version 9.60.100 Windows 2000, Windows 2003, and Windows XP (STN: 10344-9.60-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	Same as above	NA	NA
Design Document (DD)	Same as above	NA	NA
User Information Document (UID)	Same as above	NA	NA
User's Guide, GoldSim Probabilistic Simulation Environment, V. 9.60	Same as above	NA	NA
Software Validation Report (SVR)	10344-SVR-9.60-01-WIN2000	DIRS 182913	MOL.20070711.0250
Software Validation Report (SVR)	10344-SVR-9.60-01-WIN2003	DIRS 182914	MOL. 20070711.0252
Software Validation Report (SVR)	10344-SVR-9.60-01-WINXP	DIRS 182915	MOL. 20070711.0254

Table 3-9. InterpZdll_LA Software Documents

Version 1.0 Windows 2000 (STN: 11107-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	11107-SMR-1.0-00	DIRS 168988	MOL.20040130.0403
Version 1.0 Windows 2003 (STN: 11107-1.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	Same as above	NA	NA
Software Validation Report (SVR)	11107-SVR-1.0-01-WIN2003	DIRS 181092	MOL.20070220.0471

Table 3-10. MFCP_LA Software Documents

Version 1.0 Windows 2000 (STN: 11071-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	11071-SMR-1.0-00	DIRS 167597	MOL.20030529.0258
Version 1.0 Windows 2003 (STN: 11071-1.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	Same as above	NA	NA
Software Validation Report (SVR)	11071-SVR-1.0-01-WIN2003	DIRS 181113	MOL.20061218.0126

Table 3-11. MKTABLE/MkTable_LA Software Documents

Version 1.00 Windows 2000 (STN:10505-1.00-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	10505-SMR-1.00-00	DIRS 167572	MOL.20010712.0055
Version 1.0 Windows 2000 (STN:11217-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11217-RD-1.0-00	DIRS 181114	MOL.20060413.0349
Design Document (DD)	11217-DD-1.0-00	DIRS 181115	MOL.20060413.0351
User Information Document (UID)	11217-UID-1.0-00	DIRS 181116	MOL.20060413.0354
Software Validation Report (SVR)	11217-SVR-1.0-00-WIN2000	DIRS 181117	MOL.20060413.0357
Version 1.0 Windows 2003 (STN: 11217-1.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	Same as above	NA	NA
Design Document (DD)	Same as above	NA	NA
User Information Document (UID)	Same as above	NA	NA
Software Validation Report (SVR)	11217-SVR-1.0-01-WIN2003	DIRS 181118	MOL.20070208.0274

Table 3-12. MVIEW Software Documents

Version 1.0 XP (STN: 10072-4.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10072-RD-4.0-01	DIRS 174593	MOL.20050712.0023
Design Document (DD)	10072-DD-4.0-00	DIRS 174594	MOL.20050712.0025
User Information Document (UID)	10072-UID-4.0-00	DIRS 174595	MOL.20050712.0027
Software Validation Report (SVR)	10072-SVR-4.0-01-WINXP	DIRS 181119	MOL.20070417.0382

Table 3-13. PassTable1D_LA Software Documents

Version 1.0 Windows 2000 (STN: 11142-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	11142-SMR-1.0-00	DIRS 168978	MOL.20040310.0105
Version 1.0 Windows 2003 (STN: 11142-1.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	Same as above	NA	NA
Software Validation Report (SVR)	11142-SVR-1.0-01-WIN2003	DIRS 181120	MOL.20061218.0107
Version 2.0 Windows 2000 and 2003 (STN: 11142-2.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11142-RD-2.0-01	DIRS 181121	MOL.20070420.0357
Design Document (DD)	11142-DD-2.0-01	DIRS 181122	MOL.20070420.0359
User Information Document (UID)	11142-UID-2.0-00	DIRS 181123	MOL.20070420.0361
Software Validation Report (SVR)	11142-SVR-2.0-00-WIN2000	DIRS 181124	MOL.20070420.0363
Software Validation Report (SVR)	11142-SVR-2.0-00-WIN2003	DIRS 181125	MOL.20070420.0365

Table 3-14. PassTable3D_LA Software Documents

Version 1.0 Windows 2000 (STN: 11143-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	11143-SMR-1.0-00	DIRS 168981	MOL.20040317.0127
Version 1.0 Windows 2003 (STN: 11143-1.0-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	Same as above	NA	NA
Software Validation Report (SVR)	11143-SVR-1.0-01-WIN2003	DIRS 181126	MOL.20070208.0286
Version 2.0 Windows 2000 and 2003 (STN: 11143-2.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11143-RD-2.0-00	DIRS 182916	MOL.20070816.0245
Design Document (DD)	11143-DD-2.0-00	DIRS 182917	MOL. 20070816.0247
User Information Document (UID)	11143-UID-2.0-00	DIRS 182918	MOL. 20070816.0252
Software Validation Report (SVR)	11143-SVR-2.0-00-WIN2000	DIRS 182919	MOL. 20070816.0254
Software Validation Report (SVR)	11143-SVR-2.0-00-WIN2003	DIRS 182920	MOL. 20070816.0256

Table 3-15. PREWAP_LA Software Documents

Version 1.1 Windows 2000 (STN: 10939-1.1-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10939-RD-1.1-00	DIRS 181127	MOL.20060418.0163
Design Document (DD)	10939-DD-1.1-00	DIRS 181128	MOL.20060418.0165
User Information Document (UID)	10939-UID-1.1-00	DIRS 181129	MOL.20060418.0169
Software Validation Report (SVR)	10939-SVR-1.1-00-WIN2000	DIRS 181130	MOL.20060418.0171

Table 3-16. SCCD Software Documents

Version 2.01 Windows 2000 (STN: 10343-2.01-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Routine Report (SRR)	10343-SRR-2.01-00	DIRS 152499	MOL.20010205.0113
Version 2.01 Windows 2003 (STN: 10343-2.01-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Routine Report (SRR)	Same as above	NA	NA
Software Validation Report (SVR)	10343-SVR-2.01-01-WIN2003	DIRS 181277	MOL.20070209.0013

Table 3-17. SEEPAGEDLL_LA Software Documents

Version 1.2 Windows 2000 (STN:11076-1.2-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11076-RD-1.2-00	DIRS 173465	MOL.20050406.0437
Design Document (DD)	11076-DD-1.2-00	DIRS 173464	MOL.20050406.0440
User Information Document (UID)	11076-UID-1.2-00	DIRS 173463	MOL.20050406.0425
Software Validation Report (SVR)	11076-SVR-1.2-00	DIRS 173462	MOL.20050406.0429
Version 1.3 Windows 2000 (STN:11076-1.3-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	11076-RD-1.3-00	DIRS 181131	MOL.20060525.0294
Design Document (DD)	11076-DD-1.3-00	DIRS 181132	MOL.20060525.0296
User Information Document (UID)	11076-UID-1.3-00	DIRS 181133	MOL.20060525.0300
Software Validation Report (SVR)	11076-SVR-1.3-00-WIN2000	DIRS 181134	MOL.20060525.0302
Version 1.3 Windows 2003 (STN: 11076-1.3-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	Same as above	NA	NA
Design Document (DD)	Same as above	NA	NA
User Information Document (UID)	Same as above	NA	NA
Software Validation Report (SVR)	11076-SVR-1.3-01-WIN2003	DIRS 181135	MOL.20070223.0249

Table 3-18. SoilExp_LA Software Document

Version 1.0 Windows 2000 (STN: 10933-1.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Software Management Report (SMR)	10933-SMR-1.0-00	DIRS 168977	MOL.20040227.0046

Table 3-19. SZ_Convolute Software Documents

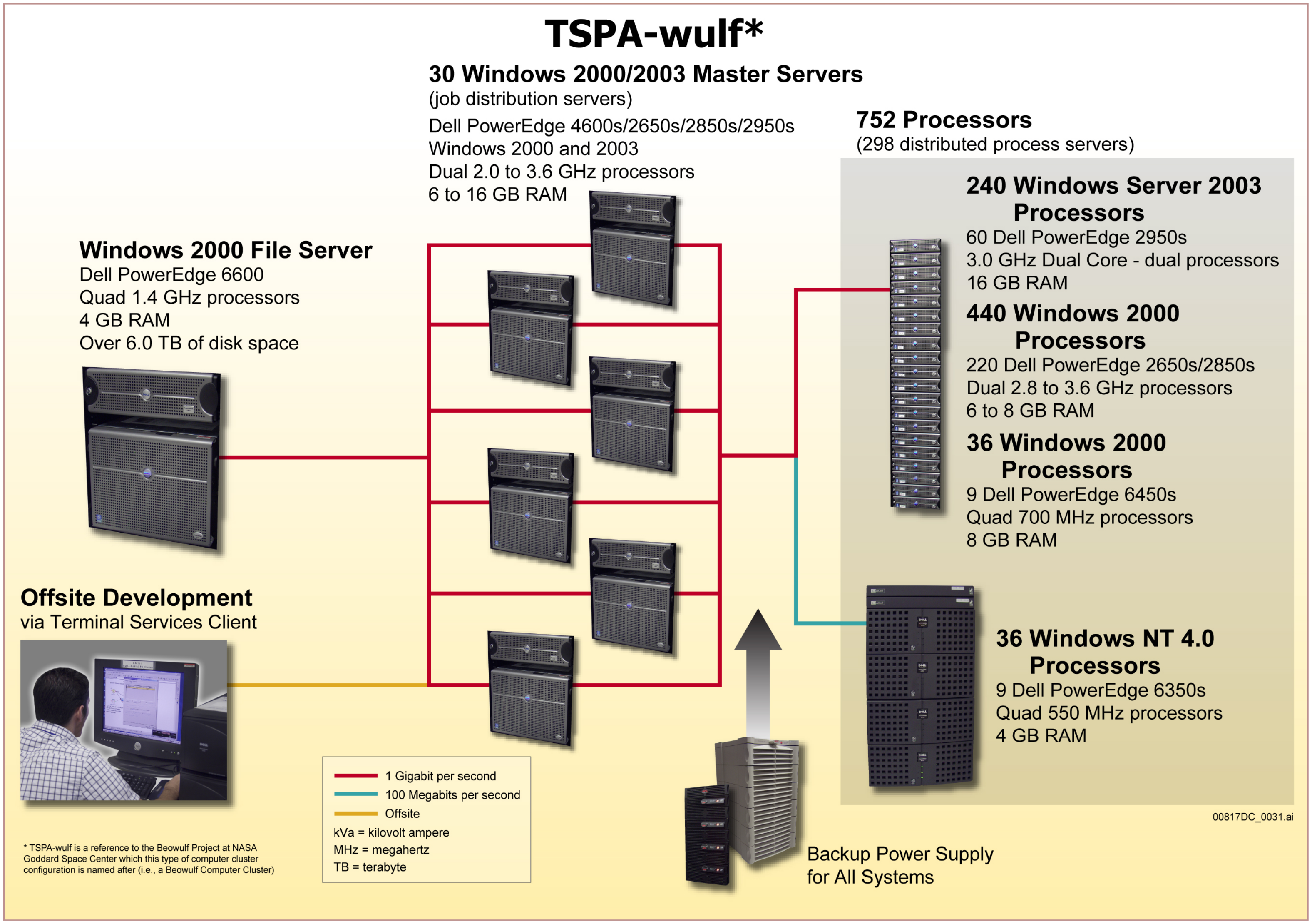
Version 3.0 Windows 2000 (STN:10207-3.0-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10207-RD-3.0-00	DIRS 167587	MOL.20030717.0478
Design Document (DD)	10207-DD-3.0-00	DIRS 167588	MOL.20030717.0479
User Manual (UM)	10207-UM-3.0-00	DIRS 167591	MOL.20030717.0483
Installation Test Process (ITP)	10207-ITP-3.0-00	DIRS 167590	MOL.20030717.0480
Validation Test Process (VTP)	10207-VTP-3.0-00	DIRS 167589	MOL.20030717.0481
Validation Test Report (VTR)	10207-VTR-3.0-00	DIRS 167593	MOL.20030717.0484
Version 3.10.01 Windows 2000 and Windows 2003 (STN:10207-3.10.01-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10207-RD-3.10-00	DIRS 181284	MOL.20061106.0218
Design Document (DD)	10207-DD-3.10-00	DIRS 181286	MOL.20061106.0219
User Information Document (UID)	10207-UID-3.10-00	DIRS 181288	MOL.20070223.0313
Software Validation Report (SVR)	10207-SVR-3.10.01-00-WIN2000	DIRS 181289	MOL.20070501.0392
Software Validation Report (SVR)	10207-SVR-3.10.01-00-WIN2003	DIRS 181290	MOL.20070501.0394

Table 3-20. TSPA_Input_DB Software Documents

Version 2.2 Windows 2000 (STN:10931-2.2-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10931-RD-2.0-00	DIRS 173449	MOL.20050131.0427
Design Document (DD)	10931-DD-2.0-00	DIRS 173450	MOL.20050131.0430
User Information Document (UID)	10931-UID-2.2-00	DIRS 181137	MOL.20060222.0419
Software Validation Report (SVR)	10931-SVR-2.2-00-WIN2000	DIRS 181139	MOL.20060222.0422
Version 2.2 Windows 2003 (STN:10931-2.2-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	Same as above	NA	NA
Design Document (DD)	Same as above	NA	NA
User Information Document (UID)	Same as above	NA	NA
Software Validation Report (SVR)	10931-SVR-2.2-01-WIN2003	DIRS 181140	MOL.20061011.0198

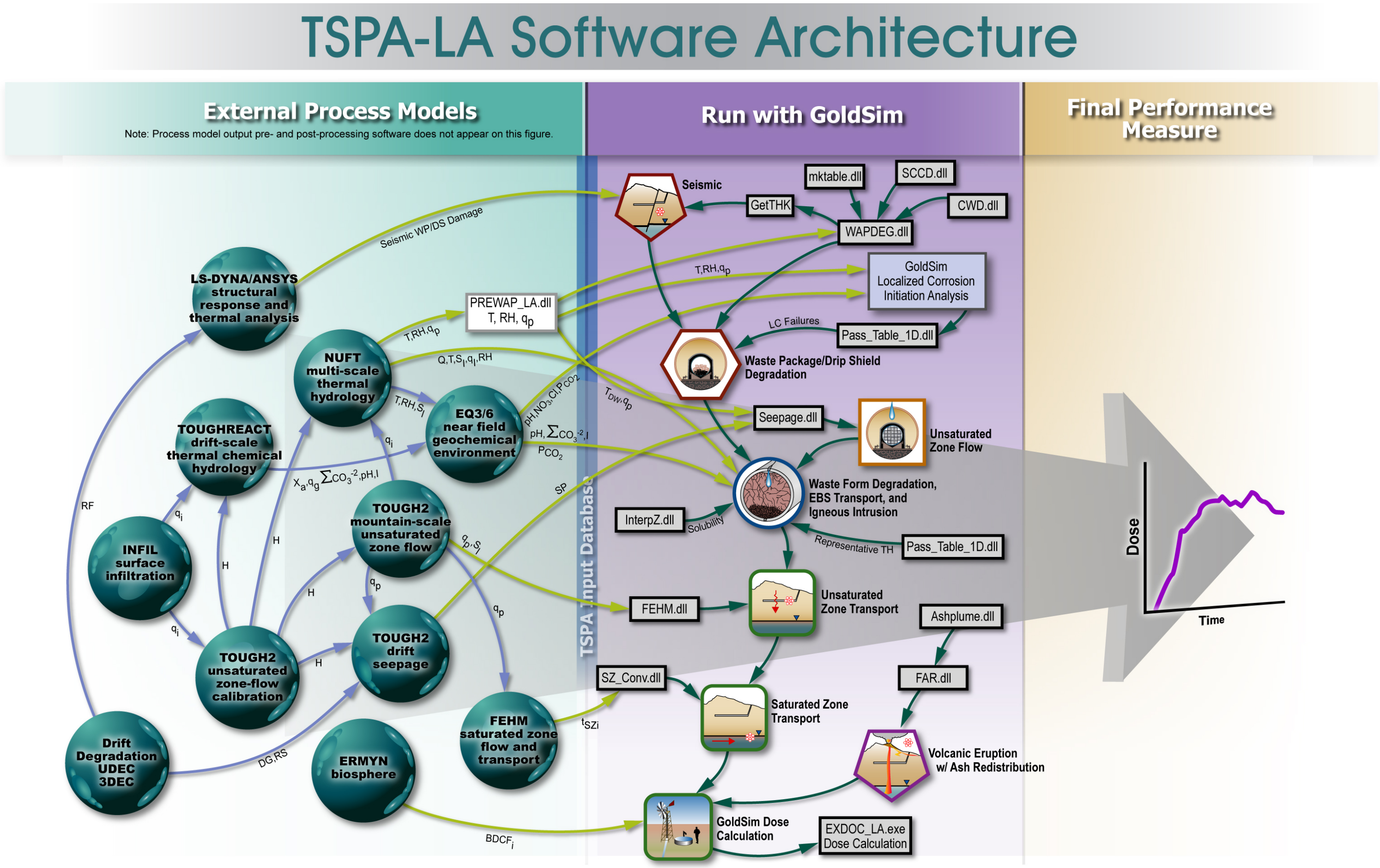
Table 3-21. WAPDEG Software Documents

Version 4.07 Windows 2000 (STN:10000-4.07-00)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	10000-RD-4.07-00	DIRS 167545	MOL.20030409.0228
Design Document (DD)	10000-DD-4.07-00	DIRS 167547	MOL.20030409.0229
User Manual (UM)	10000-UM-4.07-00	DIRS 162606	MOL.20030409.0233
Installation Test Plan (ITP)	10000-ITP-4.07-01	DIRS 167548	MOL.20030409.0231
Validation Test Plan (VTP)	10000-VTP-4.07-00	DIRS 167542	MOL.20030409.0232
Validation Test Report (VTR)	10000-VTR-4.07-00	DIRS 167554	MOL.20030409.0234
Version 4.07 Windows 2003 (STN:10000-4.07-01)			
Description	**Document ID**	**DIRS Number**	**Tracking Number**
Requirements Document (RD)	Same as above	NA	NA
Design Document (DD)	Same as above	NA	NA
Validation Test Plan (VTP)	Same as above	NA	NA
Installation Test Plan (ITP)	Same as above	NA	NA
User Manual (UM)	Same as above	NA	NA
Software Validation Report (SVR)	10000-SVR-4.07-01-WIN2003	DIRS 181141	MOL.20070417.0371



* TSPA-wulf is a reference to the Beowulf Project at NASA Goddard Space Center which this type of computer cluster configuration is named after (i.e., a Beowulf Computer Cluster)

Figure 3-1. Hardware Configuration for TSPA-LA Modeling



Output Parameters

f_S	Fraction of WPs with Seeps	q_p	Percolation Flux	q_i	Infiltration Flux	H	Hydrologic Properties
EBS	Engineered Barrier System	NO_3	Nitrate Concentration	DG	Drift Geometry	SP	Seepage Parameters
Q_S	Seep Flow Rate	T	Temperature	Cl	Chloride Concentration	RS	Rock Strength
Q	Evaporation Rate	RH	Relative Humidity	I	Ionic Strength	RF	Rockfall Size and Number
pH	pH	S_l	Liquid Saturation	t_{SZi}	Saturated Zone Transport Time		
ΣCO_3^{-2}	Carbonate Concentration	X_a	Air Mass Fraction	$BDCF_i$	Biosphere Dose Conversion Factor		
P_{CO_2}	Partial Pressure of CO_2	q_l	Liquid Flux	q_g	Gas Flux		

Legend

↗	Response Surface between Process Models	☐	Preprocessor
↗	Response Surface from Process Model to GoldSim	▨	TSPA Model DLL
↗	Connection in GoldSim		

00817DC_0093.ai

Figure 3-2. TSPA-LA Software Architecture

4. INPUTS

The TSPA-LA Model integrates several model components and submodels to simulate the performance of the repository. A numerical representation was used to implement the model with GoldSim software (see Table 3-1 for specific versions used). Inputs used by this numerical representation of the TSPA-LA Model were obtained from controlled sources maintained by the OCRWM data and information systems, such as the Controlled Documents Information System, TDMS, Technical Information Center, and other available sources such as NRC Proposed Rule 10 CFR Part 63 [DIRS 178394 and 180319]. Figure 4-1 provides an overview of the information flow for the TSPA-LA Model development and analysis. This figure illustrates the control of information as it flows from initial data collection and generation to external process models, to the GoldSim software, and finally to the TSPA-LA Model output that is submitted to the TDMS.

This section provides descriptions of the TSPA-LA Model inputs, criteria, codes and standards, and the TSPA Input Database. Model inputs consist of both direct and indirect inputs per SCI-PRO-004, *Managing Technical Product Inputs*.

4.1 DIRECT INPUTS

Direct inputs are only those parameters and their values that are used by the TSPA-LA Model to develop results and conclusions presented in this report. This information is stored in the TSPA Input Database described in Section 4.7. Table 4-1 lists the direct inputs and associates each with a reference (source) and a Parameter Entry Form (PEF) number. The respective PEF (see Section 4.3 for an overview of PEFs) contains a list and descriptions of the parameters used as input and their sources. The references shown in Table 4-1 are primarily analysis and/or model reports and DTNs associated with analysis and/or model reports. Since the direct inputs used by the TSPA-LA Model are considered technical product output and not experimental or raw field data, then in accordance with SCI-PRO-006, Attachment 2, Section 4.1, the statement in the next sentence can be accurately stated. The TSPA-LA Model does not use any data to develop the model.

When a direct input is referenced from an analysis and/or model report rather than a DTN, Table 4-1 lists the document title, document identifier (DI) number, revision number, and Document Input Reference System (DIRS) reference number for the analysis and/or model report. Similarly, when a direct input is referenced from an analysis and/or model report output DTN, Table 4-1 lists the DI, document title, DTN, and DIRS reference number for the DTN. In these cases, the DI and document title are listed to provide the connection to the analysis and/or model report that generated the DTN. The revision number for the analysis and/or model report is deliberately not shown because the Technical Database Information Form (TDIF) for the DTN will indicate the current analysis and/or model report revision number that is the source of the DTN.

In some instances, parameters are incorporated into input files or DLLs. The parameters that fall into these categories are specifically identified in the TSPA Input Database described in Section 4.7. Consequently, not all parameters in the TSPA Input Database are direct inputs, as defined by SCI-PRO-004. Thus, the PEFs containing these parameters are not presented in

Table 4-1 or Table 4-2. For example, PEF 80, shown in Table 4-2, contains parameters that are actually all of the DLLs identified in the TSPA Input Database and used in the TSPA-LA Model.

4.2 TSPA-LA MODEL GENERATED PARAMETERS

The TSPA-LA Model requires the generation of many parameters (often incorporated into large data files) that are created by preprocessing methods (i.e., created prior to running the TSPA-LA Model). These parameters are captured in output DTNs along with explanations for how they were generated. Use of these DTNs in the TSPA-LA Model is described at various locations in this document, such as Appendix F. The PEFs that reference the DTNs created by this document are listed in Table 4-2. In addition, Appendix B lists and describes all output DTNs generated by the TSPA-LA Model.

4.3 PARAMETER ENTRY FORMS

All parameter names, parameter values, and parameter references used in support of the TSPA-LA Model are documented in PEFs and contained in the TSPA Input Database. PEFs document both parameters that were downloaded from the TSPA Input Database and parameters that were entered directly into the TSPA-LA Model. Figure 4-2 provides an overview of the PEF development and update process.

Concurrent with the TSPA-LA Model development, inputs changed as analyses and/or model reports and DTNs were revised. These changes caused some PEFs to be added and others were retired from further use. As a result, some PEF numbers do not appear in Tables 4-1 and 4-2.

Generally, PEFs provide the following information:

1. List of parameters, parameter descriptions, parameter values, and references
2. Directions or roadmaps to the location(s) of the information in the references
3. Explanations of any transformations, files, or parameters created by a TSPA analyst
4. Signatures documenting that inputs were appropriately selected from analysis and/or model reports and used in the TSPA-LA Model.

The PEF contains signature lines for purposes of approval as represented on Figure 4-2. Approvals indicate the following:

- The Parameter Team Lead indicates that the PEF contains appropriate information, including the list of parameters, parameter descriptions, references where the parameters were obtained, and roadmaps describing the location of the parameters within the references.
- The TSPA analyst indicates that the PEF contains the parameters (and their associated parameter values) used as direct input to the TSPA-LA Model and any conversions made to the parameter values necessary for model input.

- The SME indicates that the PEF accurately represents the parameters (and their associated parameter values) and the references intended for TSPA-LA Model input. SMEs are generally the principal investigators that are most knowledgeable about the input parameters and their uncertainties for use in the TSPA-LA Model.
- The database administrator indicates that the parameters and parameter values are available in the TSPA Input Database in the appropriate formats defined by the software documents listed in Table 3-20.

4.4 TRACEABILITY OF INPUTS

Traceability of inputs is provided by using one or more of the following tools:

1. **DIRS Database**—DIRS is a database that contains the technical product input sources, such as direct and indirect inputs and their status.

2. **TSPA Input Database**—The TSPA Input Database (Section 4.7) provides detailed information for each parameter, such as parameter name, parameter description and type, source reference, parameter value, and verification status. When the database is downloaded into the TSPA-LA Model, this traceability information is embedded in the TSPA-LA Model as a model element.

3. **Table 4-1**—Table 4-1 lists all direct inputs used in the TSPA-LA Model and associates each direct input with a PEF.

4. **PEFs**—The PEFs collectively contain all parameters used as input to the TSPA-LA Model. Each PEF references the specific locations of the parameters within a reference document or DTN to aid in the traceability of the direct inputs. The original signed PEFs are in the records package for this document; however, the TSPA Input Database can be used to generate any PEF, as described in Section 4.7.

5. **TSPA-LA Model**—The TSPA Input Database information listed in Item 2 of Section 4.4 is embedded in the TSPA-LA Model file (e.g., parameter name, type of parameter, source reference, and parameter value).

The following examples show how the tools described above can be used to obtain documentation and demonstrate traceability:

1. **Source of any Parameter**—The source of a parameter may be obtained by accessing the reports in the TSPA Input Database.

2. **Listing of Direct Inputs**—The DIRS database can provide a list and associated status of all direct inputs. Table 4-1 also contains a list of all direct inputs and corresponding DIRS reference numbers.

3. **Location of a Parameter within the TSPA-LA Model**—A particular parameter within the TSPA-LA Model file can be located using the GoldSim search utility. Enter all or part of the parameter name in the *search* field adjacent to the binocular icon in the upper left hand corner of the TSPA-LA Model file. Pressing F3 or the Search button (i.e., the binoculars) finds the next item (element) in the browser that matches the search string.

4. **Parameters Associated with a PEF**—The list of parameters for any designated PEF can be obtained from the records package in the Records Information System (RIS) or by generating a report from the TSPA Input Database.

4.5 CRITERIA

In 10 CFR 63.102(j) [DIRS 180319], the NRC requires the DOE to complete "a performance assessment to quantitatively estimate radiological exposures to the reasonably maximally exposed individual at any time during the compliance period." The TSPA-LA Model was developed to meet this requirement.

The requirements to be addressed by this TSPA-LA are identified in the *Technical Work Plan for: Total System Performance Assessment FY 07-08 Activities* (SNL 2008 [DIRS 184920]). This subset of requirements shown in Table 4-3 was established based on the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) and is discussed in Appendix H.

4.6 CODES AND STANDARDS

No codes or standards are required for this document other than those identified in Section 4.5.

4.7 TSPA INPUT DATABASE

This section provides a summary of the TSPA Input Database. Additional detail on its design and operation can be found in the software documents listed in Section 3. The TSPA Input Database supports the TSPA-LA Model by providing the parameter values and distributions necessary for the PA analysis of the repository. The database is used to categorize, store, and retrieve fixed and distributed values of the TSPA-LA Model parameters. The database is programmed with user controls featuring read and write access and audit trails. These controls were designed to ensure the security, integrity, and traceability of the information used in the TSPA-LA Model analyses. The following sections provide a brief overview of:

- Database structure
- Database operation login
- Database forms
    - Parameter Identification Form (PIF)
    - Parameter Documentation Form (PDF)
    - Parameter Value Entry Form (PVEF)
    - PEF Information Entry Form
    - Parameter Verification Form (PVF)

- Database reports
- Database support of GoldSim.

4.7.1 Database Structure

The TSPA Input Database was developed using a commercially available desktop database manager, Microsoft Access 2000. It is a multi-user, Microsoft Windows based, relational database solution that allows data entry, viewing, and querying, as well as report preparation. The TSPA Input Database was designed and qualified in accordance with IM-PRO-004, *Qualification of Software*. The software documents listed in Table 3-20 provide details of the software design and implementation of the database. In a relational database, related information can be stored in separate tables, reducing the likelihood of redundant entries. Referential integrity relationships among tables in the TSPA Input Database are used where there is information in one table that must refer to information in another table.

Figure 4-3 illustrates the structured framework (schema) of the TSPA Input Database and the relationships among the three fundamental elements of data flow and data storage in the database. The three principal operational elements of the database are the PIF, parameter documentation form, and parameter value entry form. Each of these three database elements appears as a separate interactive screen image when the database is electronically accessed. The relationship line between these elements (Figure 4-3) automatically enforces database referential integrity by creating a foreign key constraint on the related tables. In this manner, parameter information is not duplicated across multiple tables.

4.7.2 Database Operation Login

The initial point of entry to the TSPA Input Database is the login screen, which contains a password entry feature to control access of authorized users. (Note: the database that is included with the electronic version of this document does not have password entry because it is read-only.) Each authorized user is assigned a user name, and each user name has an established password and user level. The user level (i.e., 1, 2, or 3) determines user privileges. A Level 1 user is allowed to perform data entry and updates but is not allowed to perform data verifications. A Level 2 user is allowed to view data and perform data verifications. A Level 3 user has read-only privileges.

4.7.3 Parameter Identification Form

Following login into the TSPA Input Database, the PIF (Figure 4-4) appears as the first interactive, menu-driven screen image. The PIF serves as the primary means to view existing parameters and to enter new parameters into the database. All parameters have an associated PIF accessible by selecting a parameter name from the list on the left side of the PIF. The database ensures that each parameter is assigned a unique parameter name and parameter identification. The PIF presents the PEF number that the parameter is assigned, a description of the parameter, and other attributes. The Primary Model Location field identifies the location in which the parameter is first introduced into the TSPA-LA Model as a data element. In contrast, the Other Locations field identifies the other locations in which the parameter is introduced into the

TSPA-LA Model. These locations are often difficult to ascertain due to the complexity of the model and should be viewed as general assignments.

4.7.4 Parameter Documentation Form

The parameter documentation form (Figure 4-5) is accessible from the PIF via the Documentation button. This form presents the reference information from which the parameter was obtained. The appearance of the parameter documentation form differs depending on the parameter type recorded on the PIF. For example, if the parameter type is file, two additional fields are displayed. The File Element Pathway field contains the external file pathway to the controlled data file, and the Document Signature field contains the associated audit-tracking signature number. This information is required by the GoldSim software in order to perform external file and DLL transfers. For details, see *User's Guide, GoldSim Probabilities Simulation Environment* (GoldSim Technology Group 2007 [DIRS 181727]). The effective date on the form indicates the date the parameter was entered into the TSPA Input Database. Finally, the parameter documentation form contains a hyperlink to the Automated Technical Data Tracking system to provide access directly to the DTN from which the parameters were obtained.

4.7.5 Parameter Value Entry Form

The parameter value entry from (Figure 4-6) is accessible from the parameter documentation form via the Value button. This form presents the parameter value(s). The appearance of the parameter value entry form differs depending on the parameter type recorded on the PIF. Each parameter type has a corresponding parameter value format. In addition, each parameter value has a unique component identification. For data tables, each row of data has its own component identification. For one-dimensional and two-dimensional data tables and multiple-row stochastic values, two separate forms are required. Figure 4-6 is an example of a parameter value entry form for the 1-D Table parameter type, with multiple-row stochastic values. A sequential code is assigned to each row of values in the input tables. This code is read by the GoldSim software to ensure that downloads from the TSPA Input Database are performed in the correct order.

4.7.6 Parameter Entry Form Information Entry Form

The PEF Information Entry Form (Figure 4-7) is accessible from the PIF via the Enter PEF Information button. For each PEF number, this form presents the name of the analyst(s), roadmap information, and PEF revision history. The contents and purpose of the PEF are described in more detail in Section 4.3.

4.7.7 Parameter Verification Form

The parameter verification form (Figure 4-8) is accessible from the PIF form, parameter documentation form, and parameter value entry form via the Verify button. This form presents the checker's name, date and time of verification, and any checker comments. The Editing History field shows all users and the dates and times for modifications made to the parameter information. The verification status is cleared when any parameter form is modified that affects a parameter. A cleared verification status indicates that the parameter needs to be reverified. Before downloading parameter values to the TSPA-LA Model for a PA analysis, each parameter undergoes verification to ensure that all information was correctly and completely entered. Only users with the appropriate, controlled access to the TSPA Input Database can perform data verification (Section 4.7.2).

4.7.8 Database Reports

TSPA Input Database reports are accessible from the PIF via the Report button. The following reports can be produced:

- **Alphabetized Parameter Listing**—This report is an alphabetic list of all parameters and includes parameter description, primary model location, PEF number, and reference information.
- **Parameter Listing by Analyst(s)**—This report lists all parameters for a specified TSPA analyst. The report is grouped by PEF number and primary model location and includes parameter description, input type, other model locations, reference information, and verification status.
- **Complete Parameter Listing by PEF**—This report lists all parameters by PEF number and includes parameter description, units, type, distribution, primary model location, and reference information. A count of parameter entries is displayed for each PEF grouping and for the entire database.
- **Print a PEF**—This report displays the PEF information for a selected PEF number and includes TSPA analyst, roadmap, and revision history; all parameters associated with the PEF parameter description; reference information; and any associated to be verified (TBV) references. A count of the total number of parameter entries for the PEF is printed at the end of the parameter listing.
- **List by All Locations in TSPA-LA Model**—This report lists all parameters associated with the specified TSPA-LA Model location, which includes both primary and other locations. The list includes PEF number, parameter description, input type, reference information, and whether the model location is primary. The number of parameter entries for the TSPA-LA Model location requested is reported at the end of the list.
- **List by Primary Locations in TSPA-LA Model**—This report lists all parameters associated with the specified primary model location and is grouped by reference document. The report includes parameter description, PEF number, and any associated DTN(s).
- **Report and DTN Listings**—This report lists all references cited in the PEFs and includes analysis and/or model reports by DI and document title and all associated DTNs.
- **DI–PEF List**—This report lists all parameters grouped by PEF for the selected DI. The information presented includes parameter description, primary model location, and input type. The end of each DI list includes a count of the number of PEFs and parameter entries.

- **List All Data**—This report lists all information about the selected parameter, including the parameter values.
- **List by Input Type**—This report lists all parameters associated with the selected input type. The information presented includes PEF, parameter description, primary model location, and reference information. The number of parameter entries is reported at the end of the report.

4.7.9 Database Support of GoldSim

The TSPA Input Database serves as the quality-controlled repository for the input parameters before the parameter values are downloaded to the TSPA-LA Model. The database is designed to interface with GoldSim, via ODBC, for automated downloads to the TSPA-LA Model. Upon download of the database to the TSPA-LA Model, designated content from the database is embedded in a model element.

The TSPA Input Database download provides two primary functions: (1) ensures the most recent data are being used, and (2) ensures that the correct DLLs and input files are moved from a controlled directory to the directory for the current GoldSim run.

Table 4-1. Direct Inputs

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
1	10 CFR 63	10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada	180319	NA	NA	81
2	70 FR 53313	Implementation of a Dose Standard After 10,000 Years	178394	NA	NA	90
3	ANL-EBS-MD-000003	*General Corrosion and Localized Corrosion of Waste Package Outer Barrier*	NA	MO0703PAGENCOR.001_R4	182029	5
4	ANL-EBS-MD-000003	*General Corrosion and Localized Corrosion of Waste Package Outer Barrier*	NA	MO0703PAGENCOR.001_R4	182029	7
5	ANL-EBS-MD-000003	*General Corrosion and Localized Corrosion of Waste Package Outer Barrier*	NA	MO0703PAGENCOR.001_R4	182029	85
6	ANL-EBS-MD-000003	*General Corrosion and Localized Corrosion of Waste Package Outer Barrier*	NA	MO0703PAGENCOR.001_R4	182029	117
7	ANL-EBS-MD-000004	*General Corrosion and Localized Corrosion of the Drip Shield*	NA	SN0704PADSGCMT.001_R2	182122	3
8	ANL-EBS-MD-000004	*General Corrosion and Localized Corrosion of the Drip Shield*	NA	SN0704PADSGCMT.002_R1	182188	105
9	ANL-EBS-MD-000005	*Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials*	NA	MO0702PASTRESS.002_R2	180514	4
10	ANL-EBS-MD-000005 REV 04	*Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials*	181953	NA	NA	131
11	ANL-EBS-MD-000015	*CSNF Waste Form Degradation: Summary Abstraction*	NA	MO0404ANLSF001.001_R0	169007	31
12	ANL-EBS-MD-000015 REV 02	*CSNF Waste Form Degradation: Summary Abstraction*	169987	NA	NA	82
13	ANL-EBS-MD-000016	*Defense HLW Glass Degradation Model*	NA	MO0502ANLGAMR1.016_R0	172830	32

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
14	ANL-EBS-MD-000033	*Engineered Barrier System: Physical and Chemical Environment*	NA	SN0701PAEBSPCE.001_R1	180523	75
15	ANL-EBS-MD-000033	*Engineered Barrier System: Physical and Chemical Environment*	NA	SN0701PAEBSPCE.002_R0	179425	76
16	ANL-EBS-MD-000033	*Engineered Barrier System: Physical and Chemical Environment*	NA	SN0703PAEBSPCE.006_R2	181571	77
17	ANL-EBS-MD-000033	*Engineered Barrier System: Physical and Chemical Environment*	NA	SN0703PAEBSPCE.007_R2	184141	78
18	ANL-EBS-MD-000033	*Engineered Barrier System: Physical and Chemical Environment*	NA	SN0706PAEBSPCE.016_R0	181837	104
19	ANL-EBS-MD-000033 Rev 06	*Engineered Barrier System: Physical and Chemical Environment*	177412	NA	NA	119
20	ANL-EBS-MD-000037	*In-Package Chemistry Abstraction*	NA	MO0502SPAINPCA.000_R0	172893	79
21	ANL-EBS-MD-000037	*In-Package Chemistry Abstraction*	NA	SN0702PAIPC1CA.001_R2	180451	12
22	ANL-EBS-MD-000037	*In-Package Chemistry Abstraction*	NA	SN0702PAIPC1CA.001_R2	180451	102
23	ANL-EBS-MD-000037 Rev 04 AD 01	*In-Package Chemistry Abstraction*	180506	NA	NA	136
24	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0702PA027MST.082_R0	179590	15
25	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0702PA027MST.082_R0	179590	86
26	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA011MST.006_R0	179853	16
27	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA011MST.006_R0	179853	108
28	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA012MST.007_R0	179854	17
29	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA012MST.007_R0	179854	108
30	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA013MST.008_R0	179855	18
31	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA013MST.008_R0	179855	108
32	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA014MST.009_R0	179856	19
33	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA014MST.009_R0	179856	108

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
34	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA015MST.010_R0	179857	20
35	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA015MST.010_R0	179857	108
36	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA016MST.011_R0	179858	21
37	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA016MST.011_R0	179858	108
38	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA017MST.012_R0	179859	22
39	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA017MST.012_R0	179859	108
40	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA026MST.013_R0	179981	50
41	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA034MST.016_R0	179982	23
42	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA034MST.016_R0	179982	108
43	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA035MST.017_R0	179985	24
44	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA035MST.017_R0	179985	108
45	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA036MST.018_R0	179986	25
46	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA036MST.018_R0	179986	108
47	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA037MST.019_R0	179989	26
48	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA037MST.019_R0	179989	108
49	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA038MST.020_R0	179992	27
50	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	LL0703PA038MST.020_R0	179992	108
51	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	MO0505SPAROCKM.000_R0	173893	28
52	ANL-EBS-MD-000049	*Multiscale Thermohydrologic Model*	NA	MO0703PAHYTHRM.000_R1	182093	29
53	ANL-EBS-MD-000076	*Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*	NA	MO0701PASHIELD.000_R2	180508	2
54	ANL-EBS-MD-000076	*Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*	NA	MO0701PASHIELD.000_R2	180508	118
55	ANL-EBS-MD-000076 REV 00	*Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*	178765	NA	NA	130

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
56	ANL-MGR-GS-000001	*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*	NA	LA0307BY831811.001_R0	164713	60
57	ANL-MGR-GS-000002	*Characterize Eruptive Processes at Yucca Mountain, Nevada*	NA	LA0612DK831811.001_R1	179987	62
58	ANL-MGR-GS-000003	*Number of Waste Packages Hit by Igneous Events*	NA	SN0701PAWPHIT.001_R2	182961	30
59	ANL-MGR-GS-000003	*Number of Waste Packages Hit by Igneous Events*	NA	SN0701PAWPHIT.001_R2	182961	61
60	ANL-NBS-GS-000008	*Future Climate Analysis*	NA	GS000308315121.003_R0	151139	33
61	ANL-NBS-HS-000031	*Saturated Zone Colloid Transport*	NA	LA0303HV831352.003_R0	165624	84
62	ANL-NBS-HS-000058	*Calibrated Unsaturated Zone Properties*	NA	LB0610UZDSCP30.001_R0	179180	116
63	ANL-WIS-MD-000004 REV 04	*DSNF and Other Waste Form Degradation Abstraction*	172453	NA	NA	83
64	ANL-WIS-MD-000010	*Dissolved Concentration Limits of Elements with Radioactive Isotopes*	NA	MO0702PADISCON.001_R0	179358	9
65	ANL-WIS-MD-000010	*Dissolved Concentration Limits of Elements with Radioactive Isotopes*	NA	MO0702PADISCON.001_R0	179358	107
66	ANL-WIS-MD-000010	*Dissolved Concentration Limits of Elements with Radioactive Isotopes*	NA	MO0702PAFLUORI.000_R1	181219	10
67	ANL-WIS-MD-000010	*Dissolved Concentration Limits of Elements with Radioactive Isotopes*	NA	MO0704PASOLCAP.000_R0	180389	11
68	ANL-WIS-MD-000020	*Initial Radionuclides Inventory*	NA	MO0702PASTREAM.001_R0	179925	72
69	ANL-WIS-MD-000020	*Initial Radionuclides Inventory*	NA	MO0702PASTREAM.001_R0	179925	113
70	ANL-WIS-MD-000020	*Initial Radionuclides Inventory*	NA	SN0310T0505503.004_R0	168761	74
71	ANL-WIS-MD-000021	*Cladding Degradation Summary for LA*	NA	MO0411SPACLDDG.003_R1	180755	1
72	ANL-WIS-MD-000021 REV 03 ADD 01	*Cladding Degradation Summary for LA*	180616	NA	NA	92
73	ANL-WIS-PA-000001	*EBS Radionuclide Transport Abstraction*	NA	SN0703PAEBSRTA.001_R3	183217	59

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
74	NA	*Fundamentals of Heat Transfer, 5th Edition*	163337	NA	NA	47
75	MDL-EBS-MD-000001	*In-Drift Natural Convection and Condensation*	NA	MO0703PAEVSIIC.000_R2	181990	73
76	MDL-EBS-MD-000001	*In-Drift Natural Convection and Condensation*	NA	MO0702PALOVERT.000_R2	180377	70
77	MDL-EBS-MD-000001	*In-Drift Natural Convection and Condensation*	NA	MO0702PALV010K.000_R2	180376	71
78	MDL-EBS-MD-000001 Rev 00 ADD 01	*In-Drift Natural Convection and Condensation*	181648	NA	NA	99
79	MDL-EBS-PA-000004	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	NA	MO0701PACSNFCP.000_R1	180439	53
80	MDL-EBS-PA-000004	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	NA	MO0701PAGLASWF.000_R1	180393	54
81	MDL-EBS-PA-000004	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	NA	MO0701PAGROUND.000_R0	179310	55
82	MDL-EBS-PA-000004	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	NA	MO0701PAIRONCO.000_R1	180440	56
83	MDL-EBS-PA-000004	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	NA	MO0701PAKDSUNP.000_R1	180392	57

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
84	MDL-EBS-PA-000004	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*	NA	MO0701PASORPTN.000_R1	180391	58
85	MDL-MGR-GS-000002	*Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada*	NA	LA0702PADE03GK.002_R1	179980	63
86	MDL-MGR-GS-000002	*Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada*	NA	MO0408SPADRWSD.002_R0	171751	64
87	MDL-MGR-GS-000002 Rev 03	*Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada*	177431	NA	NA	62
88	MDL-MGR-GS-000005	*Dike/Drift Interactions*	NA	LA0702PADE01EG.001_R0	179495	13
89	MDL-MGR-GS-000005	*Dike/Drift Interactions*	NA	LA0702PADE01EG.002_R0	179496	14
90	MDL-MGR-GS-000006	*Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada*	NA	MO0605SPAFORTY.000_R1	182281	65
91	MDL-MGR-GS-000006	*Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada*	NA	MO0702PAFARDAT.001_R3	182578	66
92	MDL-MGR-GS-000006	*Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada*	NA	MO0704PASCOURD.000_R1	182149	87
93	MDL-MGR-MD-000001	*Biosphere Model Report*	NA	MO0702PAGBDCFS.001_R0	179327	67
94	MDL-MGR-MD-000001	*Biosphere Model Report*	NA	MO0702PAGWPROS.001_R0	179328	68

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
95	MDL-MGR-MD-000001	*Biosphere Model Report*	NA	MO0702PAVBPDCF.000_R0	179330	69
96	MDL-NBS-HS-000006	*UZ Flow Models and Submodels*	NA	LB0612PDFEHMFF.001_R0	179296	38
97	MDL-NBS-HS-000006	*UZ Flow Models and Submodels*	NA	LB0701GTFEHMFF.001_R0	179160	39
98	MDL-NBS-HS-000006	*UZ Flow Models and Submodels*	NA	LB0701MOFEHMFF.001_R0	179297	40
99	MDL-NBS-HS-000006	*UZ Flow Models and Submodels*	NA	LB0702PAFEM10K.002_R0	179507	43
100	MDL-NBS-HS-000006	*UZ Flow Models and Submodels*	NA	LB0701PAWFINFM.001_R0	179283	42
101	MDL-NBS-HS-000008	*Radionuclide Transport Models Under Ambient Conditions*	NA	LA0408AM831341.001_R0	171584	34
102	MDL-NBS-HS-000008	*Radionuclide Transport Models Under Ambient Conditions*	NA	LA0408AM831341.001_R0	171584	98
103	MDL-NBS-HS-000008	*Radionuclide Transport Models Under Ambient Conditions*	NA	LB0701PAKDSESN.001_R0	179299	41
104	MDL-NBS-HS-000019	*Abstraction of Drift Seepage*	NA	LB0702PASEEP01.001_R0	179511	44
105	MDL-NBS-HS-000019	*Abstraction of Drift Seepage*	NA	LB0702PASEEP02.001_R1	181635	45
106	MDL-NBS-HS-000019	*Abstraction of Drift Seepage*	NA	LB0407AMRU0120.001_R0	173280	37
107	MDL-NBS-HS-000019 REV 01 ADD 01	*Abstraction of Drift Seepage*	181244	NA	NA	135
108	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	LA0701PANS02BR.003_R2	180497	35
109	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	LA0701PANS02BR.003_R2	180497	98
110	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	LA0702PANS02BR.001_R1	180322	36
111	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	LA0702PANS02BR.001_R1	180322	114
112	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	LB0702PAUZMTDF.001_R1	180776	46
113	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	LB0702PAUZMTDF.001_R1	180776	98

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
114	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	MO0704PAFEHMBR.001_R3	184647	48
115	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	MO0704PAFEHMBR.001_R3	184647	101
116	MDL-NBS-HS-000020	*Particle Tracking Model and Abstraction of Transport Processes*	NA	MO0704PAPTTFBR.002_R0	180442	49
117	MDL-NBS-HS-000020 Rev 02 AD 01	*Particle Tracking Model and Abstraction of Transport Processes*	184748 181006*	NA	NA	100
118	MDL-NBS-HS-000021	*Saturated Zone Flow and Transport Model Abstraction*	NA	SN0702PASZFTMA.001_R0	179504	51
119	MDL-NBS-HS-000021	*Saturated Zone Flow and Transport Model Abstraction*	NA	SN0702PASZFTMA.002_R1	183471	52
120	MDL-NBS-HS-000021	*Saturated Zone Flow and Transport Model Abstraction*	NA	SN0702PASZFTMA.002_R1	183471	89
121	MDL-NBS-HS-000021 Rev 03 AD01	*Saturated Zone Flow and Transport Model Abstraction*	183750 181650*	NA	NA	128
122	MDL-WIS-PA-000003	*Seismic Consequence Abstraction*	NA	MO0703PASEISDA.002_R4	183156	6
123	MDL-WIS-PA-000003	*Seismic Consequence Abstraction*	NA	MO0703PASEISDA.002_R4	183156	132
124	MDL-WIS-PA-000003	*Seismic Consequence Abstraction*	NA	MO0703PASEISDA.002_R4	183156	133
125	MDL-WIS-PA-000003 Rev 03	*Seismic Consequence Abstraction*	176828	NA	NA	134
126	TDR-TDIP-ES-000006 Rev 00	*Total System Performance Assessment Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment*	179394	NA	NA	109

Table 4-1. Direct Inputs (Continued)

Line #	Document_ID	Reference_Document	Document DIRS	DTN	DTN DIRS	PEF
127	TDR-TDIP-ES-000009 Rev 00	*Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Navy SNF Waste Package Overpack Physical Attributes Basis for Performance Assessment*	179567	NA	NA	110
128	TDR-TDIP-ES-000010 REV 00	*Total System Performance Assessment Data Input Package for Requirements Analysis for Engineered Barrier System In-Drift Configuration*	179354	NA	NA	129

* DIRS not currently in the TSPA Input Database. The new reference is evaluated in Appendix P.

Table 4-2. TSPA Generated Data Tracking Numbers Referenced by Parameter Entry Forms

Line#	Document ID	Document Title	Document DIRS	DTN	DTN DIRS	PEF
1	MDL-WIS-PA-000005	*Total System Performance Assessment Model/Analysis for the License Application*	NA	MO0707EMPDECAY.000_R0	182995	113
2	MDL-WIS-PA-000005	*Total System Performance Assessment Model/Analysis for the License Application*	NA	MO0707PERCFLUX.000_R0	183001	108
3	MDL-WIS-PA-000005	*Total System Performance Assessment Model/Analysis for the License Application*	NA	MO0707PREWAPMS.000_R0	183002	16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 108
4	MDL-WIS-PA-000005	*Total System Performance Assessment Model/Analysis for the License Application*	NA	MO0707UZKDCORR.000_R0	183003	41, 98
5	MDL-WIS-PA-000005	*Total System Performance Assessment Model/Analysis for the License Application*	NA	MO0707WPDRIPSD.000_R0	183005	88, 93, 96, 103, 117, 118
6	MDL-WIS-PA-000005	*Total System Performance Assessment Model/Analysis for the License Application*	NA	MO0708TSPAGENT.000_R0	183000	7, 8, 47, 61, 75, 86, 89, 91, 94, 95, 97, 98, 101, 102, 106, 107, 111, 112, 114, 115, 120, 121, 122, 123, 124, 125, 126, 127, 132, 133, 134

NOTE: See Appendix B for a complete listing of all DTNs that support the TSPA-LA Model.

Table 4-3. Requirements

Title	Requirement Source
Performance Objectives for the Geologic Repository after Permanent Closure	10 CFR 63.113
Requirements for Performance Assessment	10 CFR 63.114
Requirements for Multiple Barriers	10 CFR 63.115
Separate Standards for Protection of Groundwater	10 CFR 63.331
Representative Volume	10 CFR 63.332

NOTE: Requirement sources are found in 10 CFR Part 63 [DIRS 180319].

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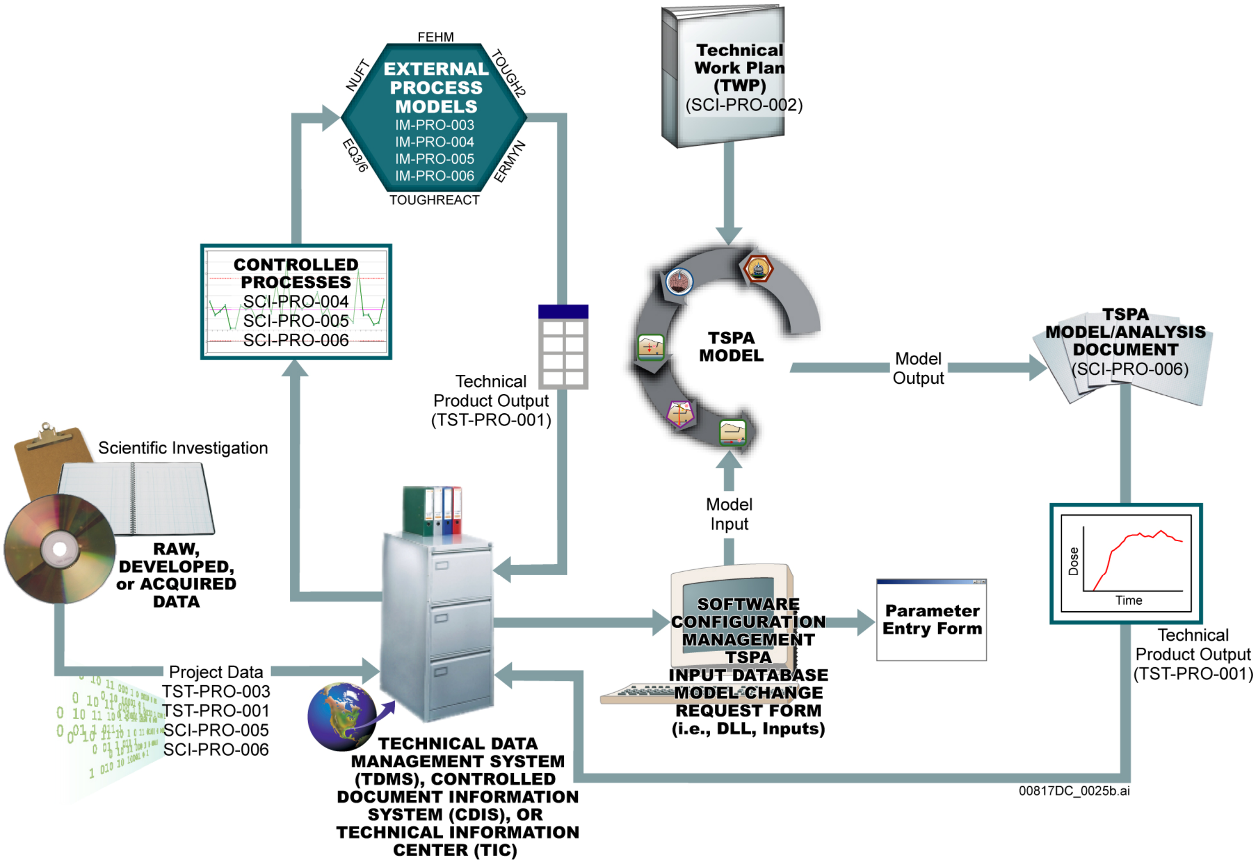


Figure 4-1. Control of Information for TSPA-LA Model Development and Analysis

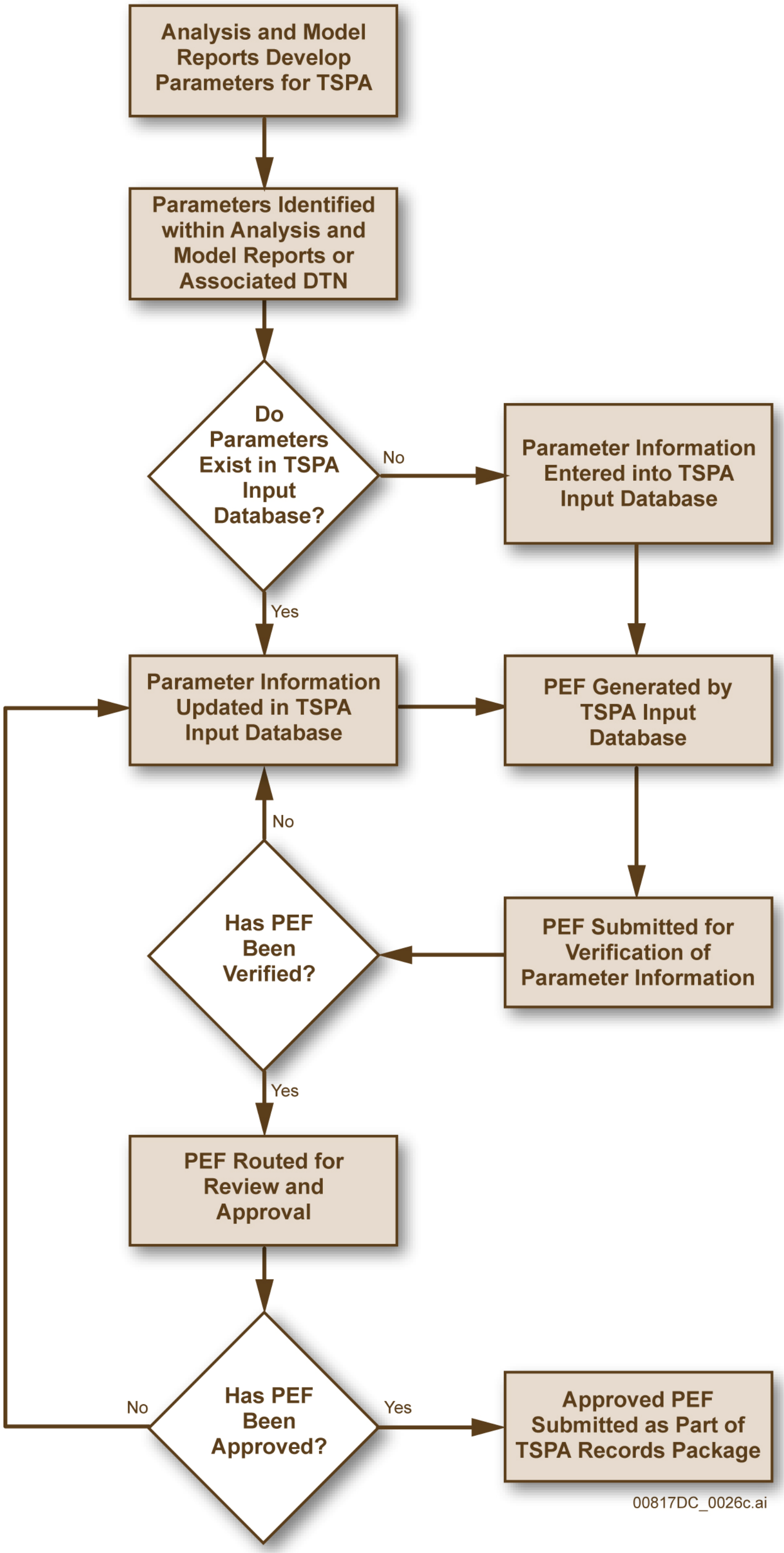
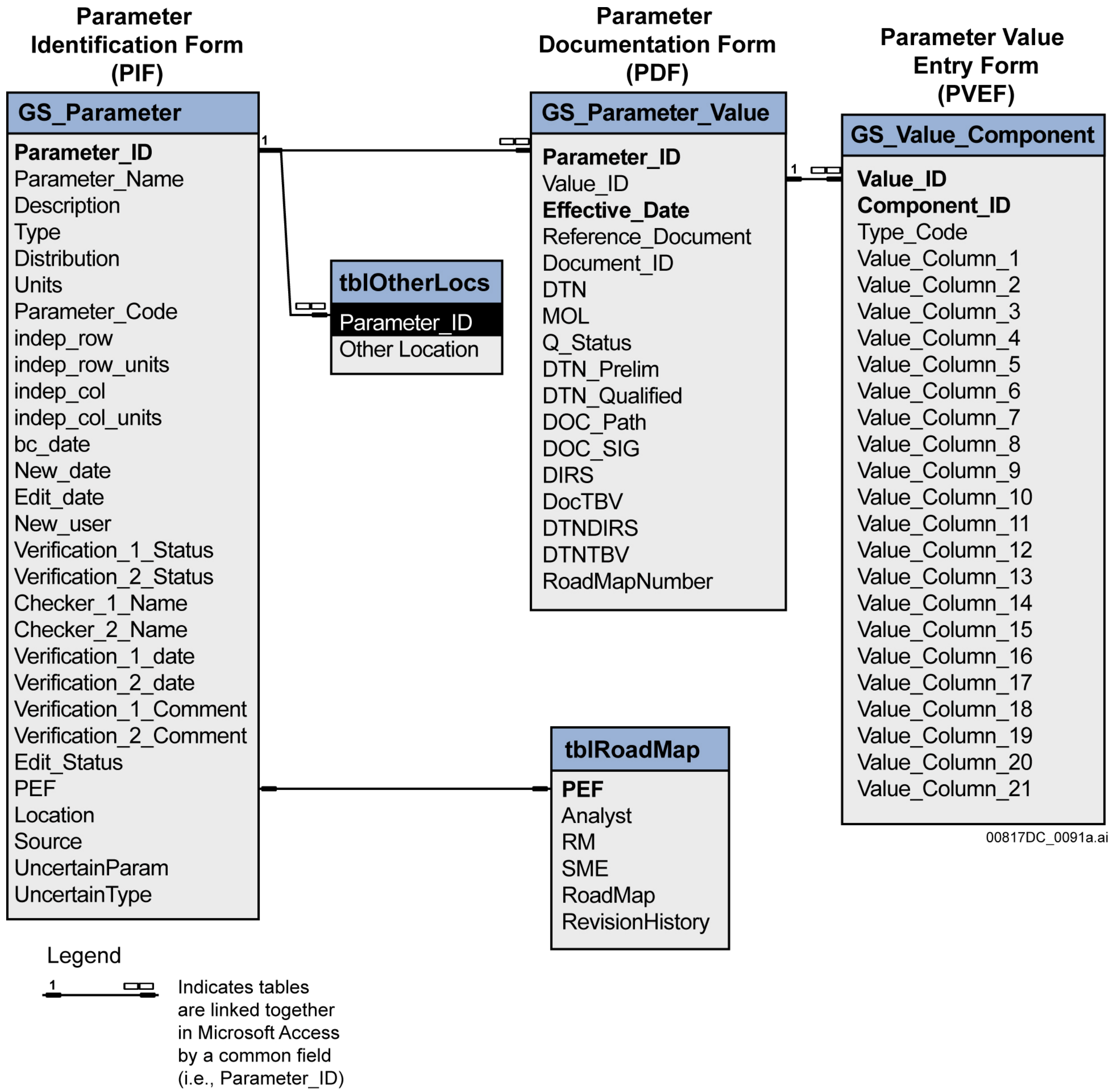
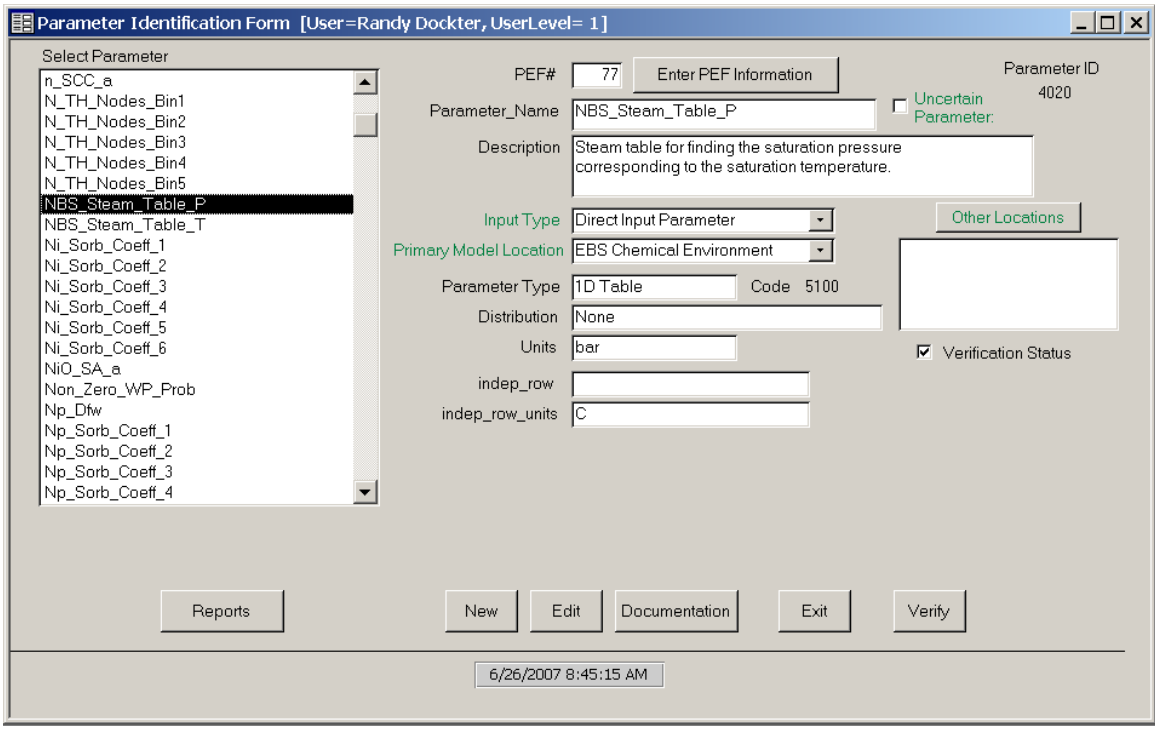


Figure 4-2. Development and Revision of Parameter Entry Forms



NOTE: These tables are described in detail in the TSPA Input Database documents listed in Section 3.

Figure 4-3. Structural Framework (Schema) for the TSPA Input Database Showing Relationships between Tables



Parameter Identification Form [User=Randy Dockter, UserLevel= 1]

Select Parameter

- n_SCC_a
- N_TH_Nodes_Bin1
- N_TH_Nodes_Bin2
- N_TH_Nodes_Bin3
- N_TH_Nodes_Bin4
- N_TH_Nodes_Bin5
- NBS_Steam_Table_P
- NBS_Steam_Table_T
- Ni_Sorb_Coeff_1
- Ni_Sorb_Coeff_2
- Ni_Sorb_Coeff_3
- Ni_Sorb_Coeff_4
- Ni_Sorb_Coeff_5
- Ni_Sorb_Coeff_6
- NiO_SA_a
- Non_Zero_WP_Prob
- Np_Dfw
- Np_Sorb_Coeff_1
- Np_Sorb_Coeff_2
- Np_Sorb_Coeff_3
- Np_Sorb_Coeff_4

PEF#: 77

Parameter ID: 4020

Parameter_Name: NBS_Steam_Table_P

☐ Uncertain Parameter:

Description: Steam table for finding the saturation pressure corresponding to the saturation temperature.

Input Type: Direct Input Parameter

Primary Model Location: EBS Chemical Environment

Parameter Type: 1D Table

Code: 5100

Distribution: None

Units: bar

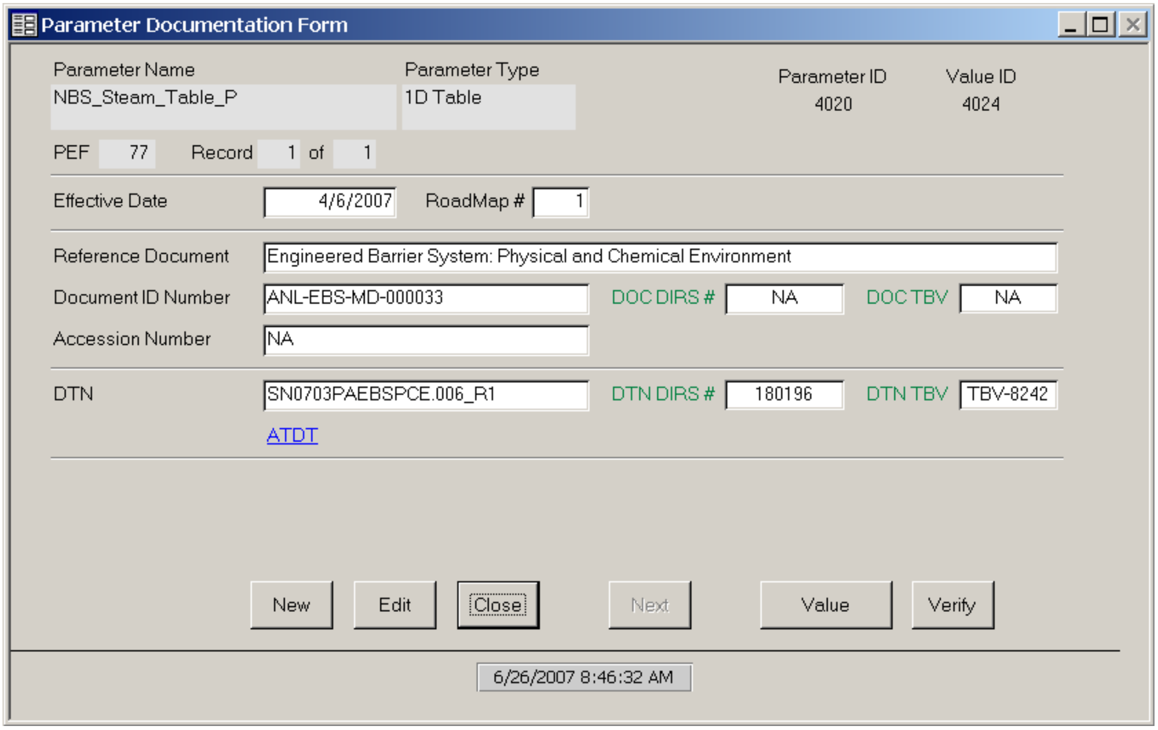
indep_row:

indep_row_units: C

☑ Verification Status

6/26/2007 8:45:15 AM

Figure 4-4. Example of a Parameter Identification Form for the TSPA Input Database



Parameter Name: NBS_Steam_Table_P

Parameter Type: 1D Table

Parameter ID: 4020

Value ID: 4024

PEF: 77

Record: 1 of 1

Effective Date: 4/6/2007

RoadMap #: 1

Reference Document: Engineered Barrier System: Physical and Chemical Environment

Document ID Number: ANL-EBS-MD-000033

DOC DIRS #: NA

DOC TBV: NA

Accession Number: NA

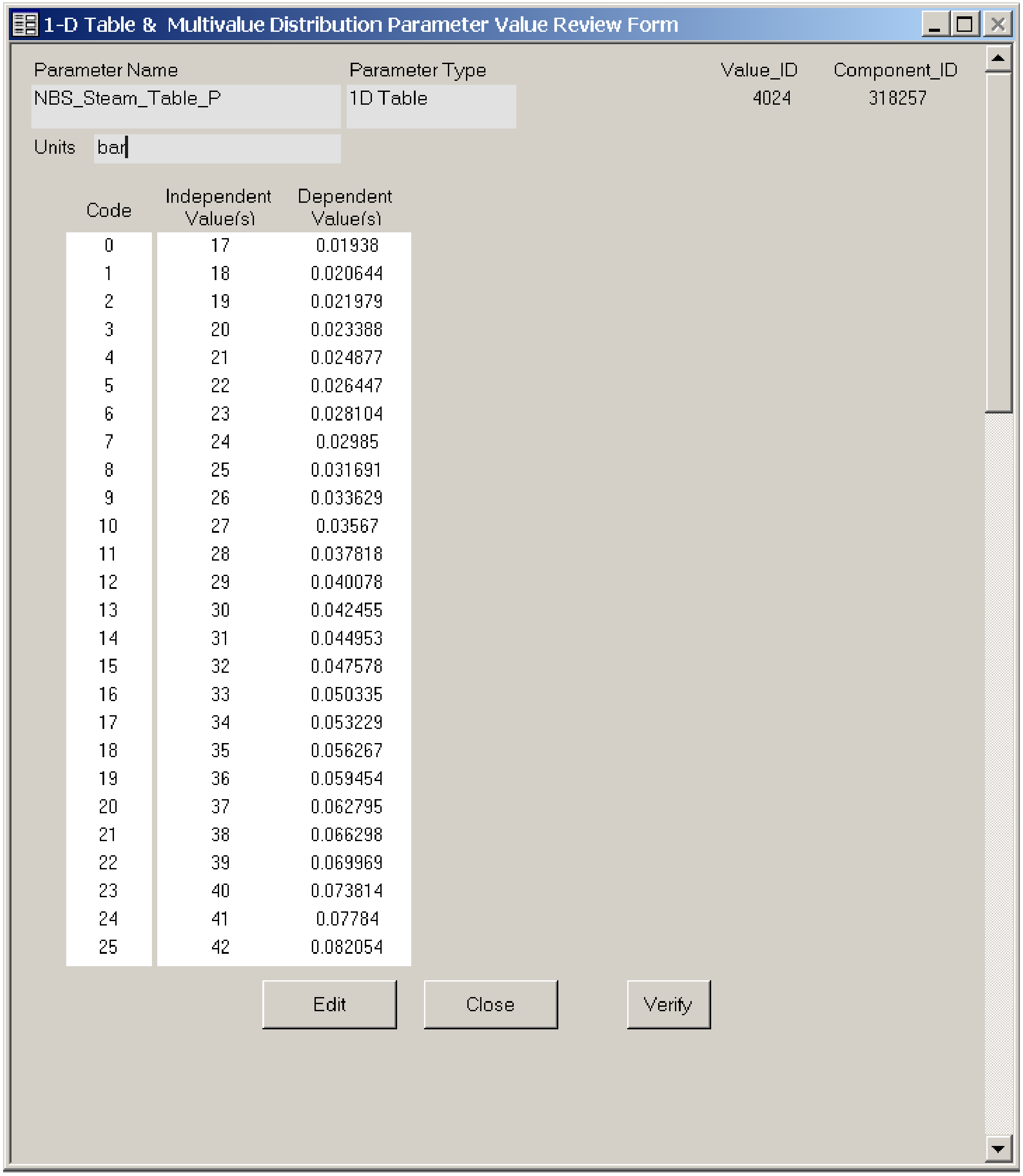
DTN: SN0703PAEBSPCE.006_R1

DTN DIRS #: 180196

DTN TBV: TBV-8242

6/26/2007 8:46:32 AM

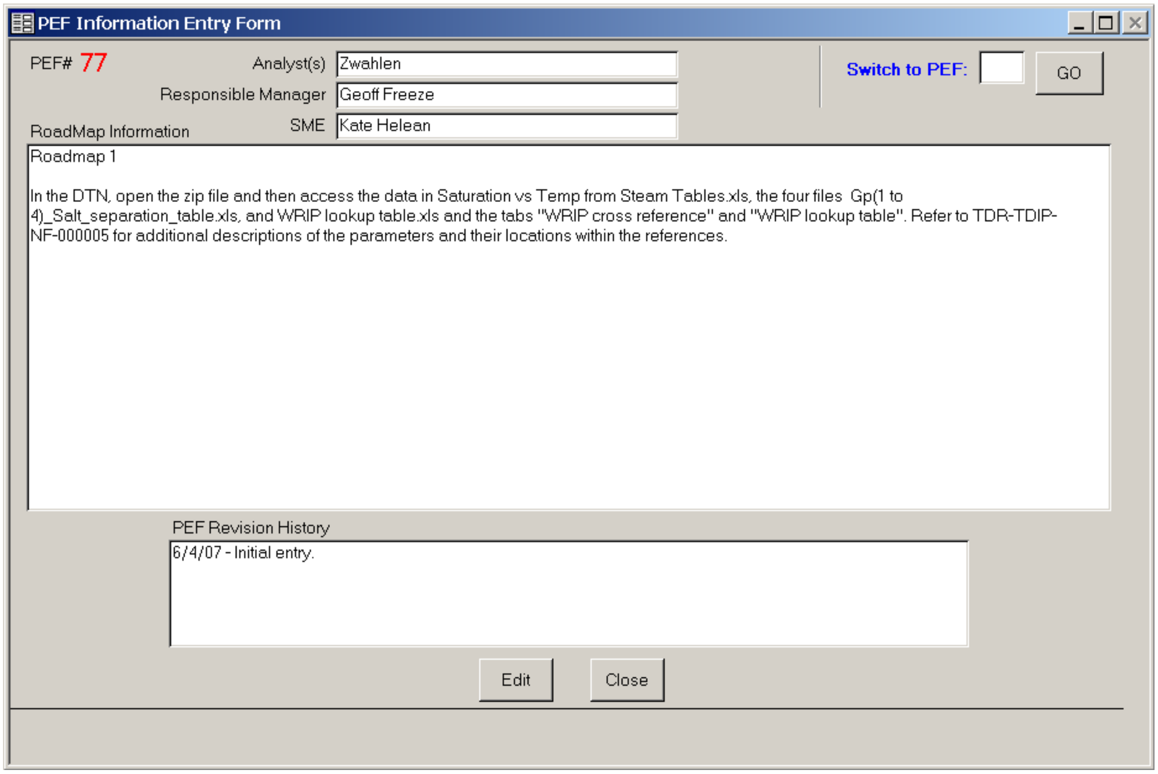
Figure 4-5. Example of a Parameter Documentation Form for the TSPA Input Database


1-D Table & Multivalue Distribution Parameter Value Review Form

Parameter Name: NBS_Steam_Table_P
Parameter Type: 1D Table
Value_ID: 4024
Component_ID: 318257
Units: bar

Code	Independent Value(s)	Dependent Value(s)
0	17	0.01938
1	18	0.020644
2	19	0.021979
3	20	0.023388
4	21	0.024877
5	22	0.026447
6	23	0.028104
7	24	0.02985
8	25	0.031691
9	26	0.033629
10	27	0.03567
11	28	0.037818
12	29	0.040078
13	30	0.042455
14	31	0.044953
15	32	0.047578
16	33	0.050335
17	34	0.053229
18	35	0.056267
19	36	0.059454
20	37	0.062795
21	38	0.066298
22	39	0.069969
23	40	0.073814
24	41	0.07784
25	42	0.082054

Figure 4-6. Example of a Parameter Value Entry Form for a One-Dimensional Data Table in the TSPA Input Database



PEF# 77

Analyst(s): Zwahlen

Responsible Manager: Geoff Freeze

SME: Kate Helean

RoadMap Information

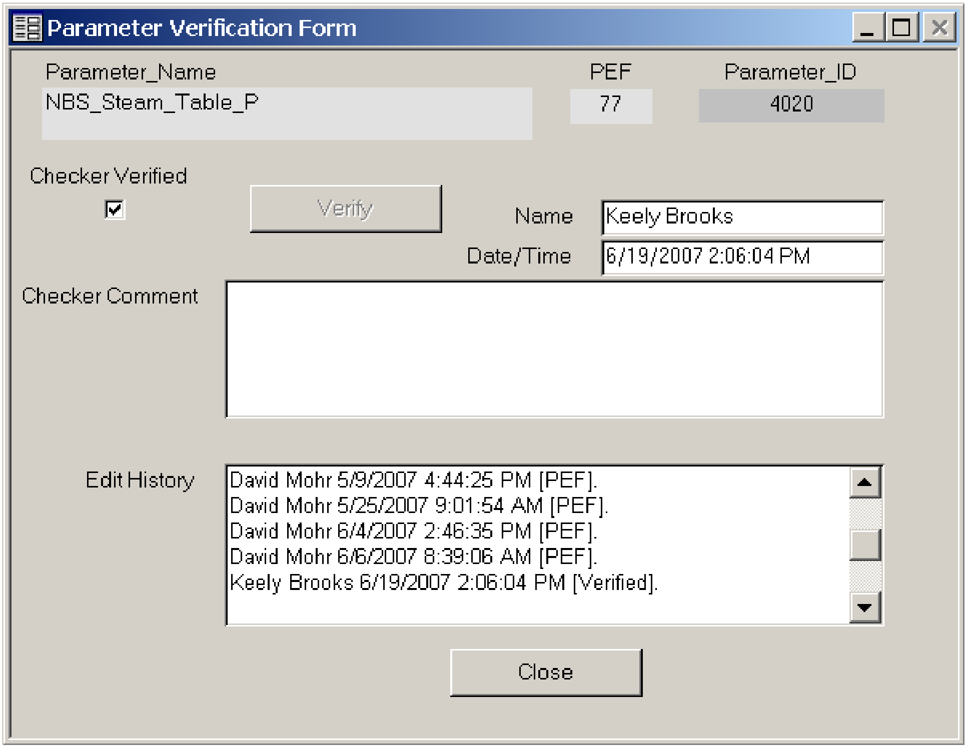
Roadmap 1

In the DTN, open the zip file and then access the data in Saturation vs Temp from Steam Tables.xls, the four files Gp(1 to 4)_Salt_separation_table.xls, and WRIP lookup table.xls and the tabs "WRIP cross reference" and "WRIP lookup table". Refer to TDR-TDIP-NF-000005 for additional descriptions of the parameters and their locations within the references.

PEF Revision History

6/4/07 - Initial entry.

Figure 4-7. Example of a PEF Information Entry Form in the TSPA Input Database



Parameter_Name: NBS_Steam_Table_P

PEF: 77

Parameter_ID: 4020

Checker Verified ☑

Name: Keely Brooks

Date/Time: 6/19/2007 2:06:04 PM

Checker Comment

Edit History

David Mohr 5/9/2007 4:44:25 PM [PEF].
David Mohr 5/25/2007 9:01:54 AM [PEF].
David Mohr 6/4/2007 2:46:35 PM [PEF].
David Mohr 6/6/2007 8:39:06 AM [PEF].
Keely Brooks 6/19/2007 2:06:04 PM [Verified].

Figure 4-8. Example of a Parameter Verification Form for the TSPA Input Database

5. ASSUMPTIONS

Section 5 presents assumptions for the TSPA-LA Model. The assumptions are as defined and described in SCI-PRO-006, *Models,* Attachment I, Definitions: "***Assumption***–A statement or proposition that is taken to be true or representative in the absence of direct confirming data or evidence, or those estimations, approximations, and/or limitations made during model development (such as when expanding the range of variables to achieve conservatism)." The TSPA-LA Model was developed by integrating assumptions, process models, abstractions, and the results of analyses documented in other project documents.

The assumptions that support the TSPA-LA consist of a subset of the assumptions from supporting analyses that, in turn, support the TSPA-LA Model. The assumptions below were judged to be either required by SCI-PRO-006 or represent assumptions not covered in Section 6.3 that describe the technical bases for the TSPA-LA Model and its submodels. In addition, Section 6.1.4 describes how the process models and submodels from the supporting analyses were integrated into the TSPA-LA Model and the reasoning behind that integration. Modeling implementation decisions (i.e., assumptions) covered in Section 6.3 are not included here because they are not considered essential to the understanding of the results of the TSPA-LA Model.

The assumptions from supporting analyses provide the conceptual underpinning of the TSPA-LA Model and show the key supporting results of these analyses that were assimilated into the TSPA-LA Model.

These assumptions are organized by scenario class, beginning with the Nominal Scenario Class and followed by the Early Failure Scenario Class, the Igneous Scenario Class, and the Seismic Scenario Class. In addition, Section 5.5 includes the assumptions for the Human Intrusion Scenario. Because the assumptions from supporting analyses were not changed in applying them to the TSPA-LA Model, the bases for these assumptions are described in the supporting analyses or are included in the descriptions of the following assumptions. Sections 6.3.1 to 6.7 discuss the conservatisms assumed to apply to the TSPA-LA Model components and scenario classes.

5.1 NOMINAL SCENARIO CLASS

5.1.1 Unsaturated Zone Flow

Assumption—Climate changes can be considered in an approximate way by imparting an instantaneous jump from one steady-state flow field to another, with a corresponding rise or fall in the water table representing the base of the UZ Transport Model Component. Shorter-term transients, such as wet and dry years or individual storm events, are assumed to be adequately captured with a model that assumes such transients can be averaged to obtain a long-term, effective, steady-state climate.

Basis—This assumption and its rationale/basis are described in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 5, Assumption 6).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.1.3

Assumption—The effect of uncertainty regarding the influence of the duration of climate periods on repository performance is negligible and, for simulation purposes, the range of durations estimated for the present-day climate state and the monsoon climate state can be simplified to the longest predicted duration of each climate state. For the present-day climate, a duration range of 400 to 600 years after emplacement and 550 years after closure is projected, and only the longest duration of 600 years after emplacement is simulated in the TSPA-LA Model. The monsoon climate period is predicted to have a duration of between 900 to 1,400 years. The TSPA-LA Model simulations use a duration of 1,400 years for the monsoon climate state.

Basis—The effect on performance is negligible based on the impact that the ranges of the durations of these climate periods have on total infiltration that is applied to the Site-Scale UZ Flow Process Model. The difference of estimated total infiltration when using the minimum climate durations as compared to the maximum projected durations of these climate periods is only about 3 percent during the 10,000-year simulation period (Section 6.3.1.2). When considering the minimum and maximum transition times, the small impact of these maximum climate-period durations on the amount of total infiltration is not likely to have a significant effect on radionuclide releases from the repository or the travel times of these radionuclides to the RMEI.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.1.2

Assumption—Per regulatory guidance, with the exception of factors related to geology, hydrology, and climate, and for the purposes of performance assessment, future conditions at the Yucca Mountain site are assumed to be the same as current conditions.

Basis—This assumption is described in NRC Proposed Rule 10 CFR 63.305(c) [DIRS 178394].

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.1.2

5.1.2 Engineered Barrier System Environment

Assumption—It is assumed that the NFC (near field chemistry) model results, calculated using averaged rock properties (mineralogy, porosity, saturation, grain density) for the four repository host units to evaluate the degree of water-rock interaction and thermal properties for the Tptpll (Topopah Spring Tuff lower lithophysal unit) lithologic unit to model development and evolution of the thermal field, are applicable to all lithologies intersected by the repository drifts.

Basis—This assumption and its rationale/basis are described in *Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412], Section 5.2.1).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.2.2

Assumption—The NFC/physical and chemical environment (P&CE) model simulations using the four starting waters adequately represent all possible seepage waters.

Basis—This assumption and its rationale/basis are described in *Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412], Section 5.2.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.4.2

Assumption—The ambient percolation-flux distribution above the repository horizon is assumed to be unaffected by mountain-scale, repository heat-driven, TH effects. Therefore, the estimated repository-scale percolation-flux distribution is assumed to be the percolation-flux distribution from the PTn to the upper Topopah Spring welded tuff (TSw) UZ Flow Model Component layer.

Basis—This assumption and its rationale/basis are described in *Multiscale Thermohydrologic Model* (SNL 2007 [DIRS 181383], Section 5.1.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.2.1

Assumption—The entire WP inventory of the repository is assumed to be emplaced at the same time.

Basis—This assumption and its rationale/basis are described in *Multiscale Thermohydrologic Model* (SNL 2007 [DIRS 181383], Section 5.2.3).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.2.1

Assumption—The EBS is assumed to be in a state of local metastable equilibrium. All aqueous and gas constituents in the TSPA-LA Model achieve and maintain local equilibrium, and most mineral phases achieve and maintain local equilibrium upon saturation. Because the reaction rates of some minerals likely to form under the Yucca Mountain geochemical conditions are slower than the scale of the modeled processes in the TSPA-LA Model, these minerals would not precipitate despite local conditions of saturation or supersaturation. However, using the assumption of metastable equilibrium, the TSPA-LA Model can be used to make steady-state predictions for nonequilibrium conditions concerning mineral stability with respect to relative humidity, provided the appropriate inputs are used.

Basis—This assumption and its rationale/basis are described in *In-Drift Precipitates/Salts Model* (SNL 2007 [DIRS 177411], Section 5.2) and applied in Section 6.6.2.6 with respect to local equilibrium and in Section 6.6.3.3 with respect to relative humidity.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.2.2

5.1.3 Waste Form Degradation and Mobilization

Assumption—Plutonium and americium sorption on HLW derived waste form colloids, steel corrosion derived iron oxyhydroxide colloids, and CSNF derived waste form colloids is modeled as irreversible.

Basis—This assumption and its rationale/basis are described in Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary (SNL 2007 [DIRS 177423], Sections 5.4, 5.5, and 6.3.12.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.7.6.2

Assumption—It is assumed that physical filtration and gravitational settling of colloids will not occur within the WPs and repository drifts.

Basis—This assumption and its rationale/basis are described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 5.7).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.7.6

5.1.4 Engineered Barrier System Flow and Transport

Assumption—It is assumed that the seepage locations in the emplacement drifts are random with respect to the locations of the WPs, but after seepage occurs, its location does not change with time. It is also assumed that fragments of the DSs that may rest on WPs, or fallen rock that may rest on DSs or WPs, do not divert any seepage flux. In addition, it is assumed that all seepage into the emplacement drifts falls on the crowns of the DSs, and in the absence of a DS, all seepage falls on the crowns of the WPs.

Basis—This assumption and its rationale/basis are described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 5.1).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.6.1

Assumption—It is assumed that there is no evaporation of the seepage water from the surfaces of the DSs.

Basis—This assumption and its rationale/basis are described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 5.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Sections 6.3.6.1 and 6.3.6.4.1

Assumption—It is assumed that evaporation of water from the surface or interior of a WP does not occur.

Basis—This assumption and its rationale/basis are described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 5.3).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Sections 6.3.6.1 and 6.3.6.4.1

Assumption—The TSPA-LA Model assumes that under low water conditions inside a WP, defined as having a relative humidity below 95 percent and a liquid influx of less than 0.1 L/year, bulk water in the WP is assumed to be unavailable for in-package chemistry calculations, and the water films are assumed to be discontinuous and not allow diffusive transport. Similarly, at and above the boiling point of water in the repository (100°C), no bulk water will be present and, thus, no transport of radionuclides could take place. For all other conditions in the repository, a thin film of adsorbed water is assumed to be present on the surfaces of internal WP components and corrosion products in a breached WP. This water film is assumed to be continuous and to behave as a bulk liquid, thus allowing radionuclides to dissolve in the water film and diffuse. Colloids are also assumed to diffuse in this water film.

Basis—This assumption and its rationale/basis are described in *In-Package Chemistry Abstraction* (SNL 2007 [DIRS 180506], Section 6.10.9.1[a]) and in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 5.5).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.7.2

Assumption—Under low-water conditions, defined as having a relative humidity below 95 percent and a liquid influx of less than 0.1 L/year, the HLW degradation rate is calculated from the aqueous degradation equations assuming a pH of 10, and the CSNF degradation rate is calculated from the aqueous degradation equations assuming a pH between 6 and 7. These pH ranges are based on limited solubility data under conditions where there is water vapor condensation on HLW and CSNF.

Basis—This assumption and its rationale/basis are described in *In-Package Chemistry Abstraction* (SNL 2007 [DIRS 180506], Sections 5.5[a] and 6.10.9.1[a]).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.7.2

Assumption—The partial pressure of O_2 in the WPs is a constant value of 0.2 bar and is equated to the partial pressure of O_2 in the emplacement drift environment, which is equal to atmospheric O_2.

Basis—This assumption and its rationale/basis are described in *In-Package Chemistry Abstraction* (SNL 2007 [DIRS 180506], Section 6.3.1.1).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.7.4.1.3

Assumption—It is assumed that no corrosion products exist in the invert.

Basis—This assumption and its rationale/basis are described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 5.6). Assuming that no corrosion products exist in the invert is a bounding assumption that reduces the potential effectiveness of the invert as a transport barrier by ignoring the potential for radionuclide sorption onto steel corrosion products.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.8.2.4 and 6.3.8.4.2

5.1.5 Unsaturated Zone Transport

Assumption—Radionuclide releases at the location of the repository can be represented stochastically by identifying regions on the basis of the predicted water flux through the medium, and placing particles randomly within this region to represent the release.

Basis—This assumption and its rationale/basis are described in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 5, Assumption 4).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.9.3

Assumption—For the purposes of computing radionuclide transport, flow through the UZ can be approximated assuming that the system (rock mass and flow conditions) has not been influenced by repository waste heat effects or drift shadow effects. Durable changes to the rock mass hydrologic properties are also assumed to be negligible.

Basis—This assumption and its rationale/basis are described in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 5, Assumption 5).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.9.4

5.1.6 Saturated Zone Flow and Transport

Assumption—The change in groundwater flow in the SZ from one climatic state to another occurs rapidly and is approximated by a shift from one steady-state flow condition to another steady-state flow condition over one timestep.

Basis—This assumption and its rationale/basis are described in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 5, Assumption 5).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.10.1

5.1.7 Biosphere

Assumption—Per regulatory guidance, it is assumed that the RMEI has a diet and living style representative of the people who now reside in the town of Amargosa Valley, Nevada.

Basis—This assumption is described in NRC Proposed Rule 10 CFR 63.312(b) [DIRS 180319]. Information on the consumption of radionuclides for the RMEI is described and tabulated in *Characteristics of the Receptor for the Biosphere Model* (BSC 2005 [DIRS 172827], Sections 6.4 and 7.1.2.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.11

Assumption—The average concentration of radionuclides in the groundwater supply of the hypothetical community of the RMEI is an appropriate estimate of radionuclide concentration for the calculation of radiological dose. To comply with 10 CFR Part 63, the average concentration of radionuclides in groundwater is calculated by considering all of the radionuclides exiting the controlled area (10 CFR 63.302 [DIRS 180319]) in a year and those contained (10 CFR 63.332(a) [DIRS 180319]) in an annual groundwater volume of 3,000 acre-feet (10 CFR 63.312(b) and 10 CFR 63.332 (a)(3) [DIRS 180319]).

Basis—This assumption and its rationale/basis are described in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 5, Assumption 3).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.3.11

5.2 EARLY FAILURE SCENARIO CLASS

Analysis of Mechanisms for Early Waste Package/Drip Shield Failure (SNL 2007 [DIRS 178765]) describes calculations related to the number of early DS and WP failures and summarizes all the assumptions related to those calculations. The assumptions for both DSs and WPs concern flaws related to Alloy 22 (UNS N06022) and titanium composition, welding, improper heat treatment, improper laser peening, improper handling, surface contamination, and incorrect DS emplacement/interlocking in the repository.

5.2.1 Drip Shield Early Failure Modeling Case

Assumption—The early-failed DSs are assumed to fail at time zero and are independently placed within the repository. In addition, it is assumed that the underlying WP fails at time zero due to localized corrosion.

Basis—The occurrence time for the early-failed DSs is a simplifying assumption used in the TSPA-LA Model in the absence of a model that explicitly accounts for the propagation of DS failures from the flaws, contamination, and improper treatment of the DSs. Furthermore, the as-received and undetected flaws, contamination, and improper treatment of the DSs are due to manufacturing and handling, and precede placement in the repository. Therefore, these assumptions are part of the as-received condition or emplacement of the DSs and are imposed as initial postclosure conditions in the TSPA-LA Model. After DS failure, there is a finite probability that the underlying WP will fail due to the initiation of localized corrosion as described in Appendix O. Instead of explicitly modeling WP failure for the situation of an early-failed DS, the TSPA-LA Model considers the bounding condition that the underlying WP is failed due to localized corrosion at the same time as the DS.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.4.1

5.2.2 Waste Package Early Failure Modeling Case

Assumption—The early-failed WPs are assumed to fail at time zero and are independently placed within the repository.

Basis—The occurrence time for the early failed WPs is a simplifying assumption used in the TSPA-LA Model that explicitly accounts for the propagation of WP failures from the as-received and undetected flaws, contamination, and improper treatment of the WPs. Furthermore, the flaws, contamination, and improper treatment of the WPs are due to manufacturing and handling, and precede placement in the repository. Therefore, these assumptions are part of the as-received condition of the WPs and are imposed as initial postclosure conditions in the TSPA-LA Model.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.4.2

5.3 IGNEOUS SCENARIO CLASS

5.3.1 Igneous Intrusion Modeling Case

Assumption—The permeability of any cooled igneous rock that has invaded emplacement drifts is assumed to be the same as that of the bulk host rock, and does not impede flow.

Basis—Natural analogs indicate that a number of different processes could lower permeabilities in the intrusions immediately in contact with a host rock (Lichtner et al. 1999 [DIRS 121006], pp. 8 and 9; Frankel 1967 [DIRS 168717]). However, the extent or uniformity of any changes to the permeability of the intrusion is not known locally. Therefore, it is assumed that hydraulic properties of the cooled intrusion are the same as those of the host rock. This assumption is necessary for the EBS and UZ flow submodels. This assumption is reasonable, technically defensible, and conservative and does not need further justification.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.5.1

Assumption—In the Igneous Intrusion Modeling Case, when any main, drift, turnout, or other extension in the repository is simulated to be hit by a dike, then all WPs in the entire repository are considered to fail.

Basis—This assumption is described in *Number of Waste Packages Hit by Igneous Events* (SNL 2007 [DIRS 177432], Section 5.1).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Sections 6.5.1.1

Assumption—In the Igneous Intrusion Modeling Case, the DOE-owned high-level waste glass waste form is assumed to instantaneously degrade releasing radionuclides from the glass matrix.

Basis—During an igneous intrusion, glass is expected to melt and resolidify as the drift cools (SNL 2007 [DIRS 177430], Section 6.4.8.3.3). During the melting process, volatile radionuclides may be released. As the glass cools, new crystalline and glass phases may form that may degrade slower or faster than the original glass phase (BSC 2004 [DIRS 169988], Section 6.5.5). To bound the uncertainty in the release fraction of the volatile radionuclides and in the degradation rates of radionuclide-containing phases, it is assumed that the glass will degrade instantaneously during an igneous intrusion.

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.5

5.3.2 Volcanic Eruption Modeling Case

Assumption—In the Volcanic Eruption Modeling Case, when a waste emplacement drift is hit by a conduit, then only the number of waste packages that can fit within the profile (footprint) of the conduit are considered to fail.

Basis—This assumption is described in *Number of Waste Packages Hit by Igneous Events* (SNL 2007 [DIRS 177432], Section 5.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Sections 6.5.2.1.1

Assumption—The ASHPLUME code (ASHPLUME_DLL_LA V.2.1, STN: 11117-2.1-01 [DIRS 180147]) assumes that volcanic eruptions in the Yucca Mountain repository are violent Strombolian eruptions for the entire duration of the explosive phase. Erupted magma is presumed to be fragmented and dispersed in the convective plume for the entire duration of the eruption. This assumption is conservative in that it maximizes the potential for ash and waste dispersal during Strombolian activity.

Basis—This assumption and its rationale/basis are described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 177431], Section 5.1.1).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.5.2

Assumption—The waste entrained in a volcanic eruption is assumed to be instantaneously fragmented and dispersed in the same manner as the erupted magma.

Basis—For the purpose of estimating waste-particle diameters in the eruptive environment, all waste is assumed to be unaltered CSNF physically disaggregated to a size range that approximately relates to fuel form grain size. If partly or wholly assimilated into the magma melt, the unaltered glass waste forms are likely to have particle diameters comparable to those of the ash particles, which are larger than the values used for spent fuel. The waste particles are transported by combining with ash particles of equal size of larger, and the ash-dispersal model assumes that fuel in the affected WPs is available for entrainment in the ash plume as finely-divided particles with diameters in the range of 1 to 2,000 μm, with a mean of 30 μm. The waste mass is distributed among the ash mass based on relative particle sizes. These assumptions are described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 177431], Sections 1, 5.1.2, 5.2.4, 5.2.5, and 6.5.2.6).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.5.2 and the GoldSim Model File

Assumption—Climatic change is assumed not to significantly affect wind speed and direction. The magnitude of short-term variability in wind speed and direction, which is included in the data that characterize present wind conditions, is assumed to be significantly greater than long-term variability introduced by potential future climatic changes.

Basis—This assumption and its rationale/basis are described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 177431], Section 5.2.1).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.4.2

5.4 SEISMIC SCENARIO CLASS

Assumption—Seismic events occur in a random manner, following a Poisson process, over long periods of time.

Basis—This assumption and its rationale/basis are described in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 5.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.6.1.3

Assumption—Waste package internals are assumed to degrade as structural elements after the outer corrosion barrier (of a WP) is first damaged by a seismic event. More exactly, the internals degrade as a structural component for the TSPA-LA Model by the time of the next seismic event after the first seismic event that breaches a WP.

Basis—This assumption and its rationale/basis are described in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 5.4).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Sections 6.6.1.1 and 6.6.1.2

5.5 HUMAN INTRUSION SCENARIO

Assumption—The NRC adopts language from the EPA Proposed Rule 40 CFR 197.26 [DIRS 155216] that describes the assumptions related to a stylized human intrusion scenario. The DOE used the following assumptions leading to an estimate of the dose to any RMEI from a human intrusion (NRC Proposed Rule 10 CFR 63.322 [DIRS 180319]):

a. "There is a single human intrusion as a result of exploratory drilling for ground water;

b. The intruders drill a borehole directly through a degraded waste package into the uppermost aquifer underlying the Yucca Mountain repository;

c. The drillers use the common techniques and practices that are currently employed in exploratory drilling for ground water in the region surrounding Yucca Mountain;

d. Careful sealing of the borehole does not occur, instead natural degradation processes gradually modify the borehole;

e. No particulate waste material falls into the borehole;

f. The exposure scenario includes only those radionuclides transported to the saturated zone by water (e.g., water enters the waste package, releases radionuclides, and transports radionuclides by way of the borehole to the saturated zone); and

g. No releases are included which are caused by unlikely natural processes and events."

Basis—These assumptions are described in NRC Proposed Rule 10 CFR 63.322 [DIRS 180319]. Information on the consumption of radionuclides for the RMEI is described and tabulated in *Characteristics of the Receptor for the Biosphere Model* (BSC 2005 [DIRS 172827], Sections 6.4 and 7.1.2.2).

Supports Total System Performance Assessment Model/Analysis for the License Application in: Section 6.7

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