ENCLOSURE 1

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (RESPONSE TO TSPAI 1.02)

Note Regarding the Status of Supporting Technical Information

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ENCLOSURE 1

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (RESPONSE TO TSPAI 1.02)

BACKGROUND

Agreement was reached for Total System Performance Assessment and Integration (TSPAI) 1.02 during the Technical Exchange and Management Meeting on Total System Performance Assessment and Integration held August 6 through 10, 2001 in Las Vegas, Nevada. The U.S. Nuclear Regulatory Commission (NRC) documented the agreement in a letter dated August 23, 2001 (Reamer 2001).

The wording of the agreement is as follows:

TSPAI 1.02

> Provide a discussion of the following in documentation of barrier capabilities and the corresponding technical bases: (1) parameter uncertainty, (2) model uncertainty (i.e., the effect of viable alternative conceptual models), (3) spatial and temporal variability in the performance of the barriers, (4) independent and interdependent capabilities of the barriers (e.g., including a differentiation of the capabilities of barriers performing similar functions), and (5) barrier effectiveness with regard to individual radionuclides. Analyze and document barrier capabilities, in light of existing data and analyses of the performance of the repository system.
>
> DOE will provide a discussion of the following in documentation of barrier capabilities and the corresponding technical bases: (1) parameter uncertainty, (2) model uncertainty (i.e., the effect of viable alternative conceptual models), (3) spatial and temporal variability in the performance of the barriers, (4) independent and interdependent capabilities of the barriers (e.g., including a differentiation of the capabilities of barriers performing similar functions), and (5) barrier effectiveness with regard to individual radionuclides. DOE will also analyze and document barrier capabilities, in light of existing data and analyses of the performance of the repository system. The information will be documented in TSPA for any potential license application expected to be available in FY 2003.

RESPONSE

The U.S. Department of Energy (DOE) has addressed the following with respect to barrier capabilities and their corresponding technical bases:

1. Parameter uncertainty is accounted for by developing distributions of values for imprecisely known parameters, rather than using single values. Each distribution describes a range of values, within which the true value is expected to fall.

2. Model uncertainty (i.e., the effect of viable alternative conceptual models), is considered in the TSPA-LA model by developing and evaluating alternative conceptual models. The alternative conceptual model that best fits with the current state of knowledge is used in the TSPA-LA model. When multiple conceptual models are plausible, a conservative model is chosen.

3. Spatial and temporal variability in the performance of the barriers is addressed by performing sufficient runs of the TSPA model to ensure the output is reduced to a stable value over space, time, or both.

4. Independent and interdependent capabilities of the barriers (e.g., including a differentiation of the capabilities of barriers performing similar functions), is addressed by evaluating the capability of each barrier with respect to flow and (or) transport. The barriers are then evaluated interdependently for their capabilities with respect to flow and (or) transport as a total system.

5. Barrier effectiveness with regard to individual radionuclides is addressed for the rate of release of radionuclides from the waste and the rate of movement of radionuclides from the repository for the Engineered Barrier System and for the release rate of radionuclides to the water table and the release rate of radionuclides to the accessible environment for the Lower Natural Barrier.

DOE also analyzed and documented barrier capabilities in light of existing data and analyses of the performance of the repository system. These discussions and analyses are documented in the TSPA-LA, which will be available at license application.

BASIS FOR THE RESPONSE

Section 6 of the TSPA-LA describes in detail the principal model components that are combined to evaluate repository system performance for nominal and disruptive event scenario classes and the treatment of uncertainty in the models. Each of the component models included in the TSPA-LA model quantifies uncertainty in the underlying processes and input parameters.

Section 8 of the TSPA-LA describes in detail the forecasted total system performance of the repository system at Yucca Mountain, including the independent and interdependent capabilities of the barriers, as well as the barrier effectiveness with regard to individual radionuclides.

Input uncertainty in TSPA-LA is explicitly presented in the TSPA-LA model by assigning empirical probability distributions to uncertain parameters. Because many of the TSPA-LA model inputs are uncertain, the TSPA-LA model uses a probabilistic framework to implement the model components. The probabilistic framework used in TSPA-LA calculations is a well-established methodology for incorporating the effects of uncertainties in scenarios, conceptual models, and parameters. Monte Carlo simulation, the most commonly employed technique for implementing the probabilistic framework in engineering and scientific analyses, is a numerical method for solving problems by random sampling. This method, as used in the TSPA-LA, allows a full mapping of the uncertainty in model parameters (inputs) and future system states (scenarios), expressed as probability distributions, into the corresponding uncertainty in model predictions (output), which is also expressed in terms of a probability distribution. Uncertainty in the model outcome is quantified via multiple model realizations using parameter values and future states drawn randomly from prescribed probability distributions.

Conceptual model uncertainty has been considered in TSPA-LA by developing and evaluating alternative conceptual models (ACMs). Conceptual model uncertainty is addressed by evaluating plausible ACMs; the ACM that best fits with the current state of knowledge is used in the TSPA-LA model. When multiple conceptual models are plausible, either a conservative model is chosen (in the sense that the conservative model will result in a calculation of reduced performance, e.g., higher dose) or the ACMs are weighted and considered in the TSPA-LA. No ACMs were recommended for inclusion in the TSPA-LA model.

In the context of the component models of the TSPA-LA, epistemic uncertainty and variability are treated as follows. Epistemic uncertainty associated with the selection of parameter values is accounted for by developing distributions of values for important and imprecisely known parameters rather than using single values. Each distribution describes a range of values within which the true value is believed to fall, with an expected value that corresponds to the best estimate of the true value. Not all parameters in the TSPA-LA require uncertainty distributions. Single values are used to describe properties that are well known or for which uncertainty has been shown to have little or no effect on overall performance. In cases where realistic uncertainty distributions or parameter values cannot be adequately justified based on available information, parameter distributions or values may be chosen that are deliberately conservative, in the sense that they result in a calculation of performance that is poorer than would result from more realistic input values. In contrast, variability in a quantity is characterized in TSPA-LA as a function of space and/or time. For some quantities, functions of the form are used as input to TSPA-LA; for other quantities, spatial and/or temporal variability is reduced to an expected value over space and/or time, and then this expected value is used as input to the TSPA-LA.

The repository system consists of the natural barriers and the engineered barrier system. The natural barrier above the repository (the Upper Natural Barrier) consists of the topography and surface soils of the mountain, the unsaturated tuff units above the repository and to the repository horizon. The natural barrier below the repository (the Lower Natural Barrier) consists of the saturated and unsaturated volcanic rocks and alluvial material below and downgradient from the repository to the accessible environment. The Engineered Barrier System consists of the drip shields, waste packages, waste package pallets, waste forms, cladding, drift invert, emplacement drifts, and emplacement drift closures.

UPPER NATURAL BARRIER

The Upper Natural Barrier affects the rate of water that can contact the features of the Engineered Barrier System (notably the drip shield, waste package, and cladding). A convenient and comparable measure of water movement in the Upper Natural Barrier is the flux of that water presented in millimeters per year. Annual precipitation rates are generally presented in millimeters per year, and using this common reference point allows for direct evaluation of the Upper Natural Barrier in reducing the flux of water that may contact the Engineered Barrier System. Because the Engineered Barrier System is located 200 to 400 m beneath the ground surface in excavated drifts, the amount of water flux that may contact the Engineered Barrier System is significantly reduced.

For the Upper Natural Barrier, infiltration and unsaturated zone flow uncertainties have been considered in the capability of the barrier.

The climate analysis model *Future Climate Analysis* (BSC 2003a) and infiltration models *Simulation of Net Infiltration for Modern and Potential Future Climates* (BSC 2003b) and *Analysis of Infiltration Uncertainty* (BSC 2003c) are based on extensive data collection and analysis of pertinent climatological and infiltration data. The climate analysis involves interpretation of paleoclimate data and acceptance of assumptions concerning earth orbital parameters in order to forecast future climatic conditions at Yucca Mountain. The infiltration model involves intensive measurement of system characteristics, parameterization of measurements, and development of a numerical model to calculate infiltration for present-day and possible future climatic conditions (BSC 2003b). Uncertainty in parameter values and analysis model approach were considered in the climate analysis (BSC 2003a, Section 6.6) and the infiltration model (BSC 2003c, Section 6.6).

Conceptual and numerical models are used to describe unsaturated zone flow in *UZ Flow Models and Submodels* (BSC 2004a, Section 6). To accommodate both variability and uncertainty in the description of the site, many of the input parameters to the unsaturated zone flow model (BSC 2004a, Section 4) are defined as probabilistic distributions. The use of probabilistic representations of parameter values allows a large range of uncertainty to be directly incorporated into process and performance assessment models. The explicit inclusion of uncertainty in terms of probability distributions for parameter values is reflected in the broad range of calculated flow and seepage rates. The model projections for unsaturated zone flow are calibrated and compared to geologic data in *Calibrated Properties Model* (BSC 2003d, Section 6.3), such as the groundwater chemistry and ages, to ensure that results are consistent with the known characteristics of the groundwater flow system in the vicinity of Yucca Mountain. Uncertainties in the percolation flux due to flow focusing are addressed through the parameters of the active fracture model (BSC 2004a, Section 6.8), and these parameters are adjusted to provide consistency with measurements that implicitly take into account flow focusing.

Projections of seepage are compared with measurements of the results of seepage tests. The measurements provide a way to take into account the potential effect on seepage estimates of film flow on the walls of the drift. The seepage model *Seepage Calibration Model and Seepage Testing Data* (BSC 2004b) does not explicitly account for this potential. However, measured seepage rate data reflect effects of film flow occurring in the test so that effective capillary-strength and permeability parameters take into account film flow. Seepage predictions made with the model *Abstraction of Drift Seepage* (BSC 2004c) capture film flow effects over the range of the measurements.

Seepage predictions are based on a process model that is calibrated with experimental data (BSC 2004b, Section 6.3). The measurements of seepage into niches account for medium-scale roughness from rockfall and large lithophysal cavities. Small-scale roughness is implicitly accounted for in the discretization of the numerical model *Seepage Model for PA Including Drift Collapse* (BSC 2004d, Section 6.4).

ENGINEERED BARRIER SYSTEM

The Engineered Barrier System provides two separate barrier functions: (1) to prevent movement of water to the waste and (2) to substantially reduce the rate of release of radionuclides from the waste.

The Engineered Barrier System's ability to prevent movement of water to the waste is directly affected by three features: the drip shield, the waste package, and the cladding of spent nuclear fuel. The degree of drip shield and waste package degradation controls the amount and rate of water that may enter the waste package and potentially allow for the degradation of the waste form. Assessment of the drip shield, waste package, and cladding performance includes analysis of the in-drift physical and chemical environment, the relevant modes of degradation, and the associated data and model uncertainties.

Physical conditions, such as temperature and relative humidity at various locations within the drift, including the drip shield and waste package, are extracted from the multiscale thermal-hydrologic model. This model incorporates the effects of parametric uncertainty and variability by simulating five cases combining different values of infiltration flux and host-rock thermal conductivity (BSC 2004e, Sections 6.3 and 8.2). It also includes the probabilities associated with each case, as well as fully representing the influence of the edge-cooling effect and waste-package-to-waste-package variability in heat output. Model uncertainty is evaluated through several alternative conceptual models, as well as comparisons to thermal field tests (BSC 2004e, Sections 6.4, 7, and 8.2). Details of the multiscale thermal-hydrologic model and its treatment and propagation of data and model uncertainty are located in *Multiscale Thermohydrologic Model* (BSC 2004e).

The in-drift chemical environment affects the chemistry of the water contacting the drip shield and waste package surfaces, as well as the water in the invert before radionuclide release. The TSPA-LA predicts aqueous chemistries through implementation of the seepage evaporation and the dust deliquescence abstractions, which are documented in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004f). These abstractions consist of lookup tables that provide a range of possible aqueous chemistries given either dripping conditions (seepage evaporation) or nondripping conditions (dust deliquescence). Sufficient information is provided to determine whether aqueous conditions exist, as well as key compositional indicators to determine where such conditions do exist. The uncertainty associated with these lookup tables is propagated through additional tables that capture geochemistry modeling uncertainty (BSC 2004g, Section 7.5) and uncertainty in the binning procedures used to reduce the number of distinct aqueous chemistries (BSC 2004f, Section 6.12.3).

To capture parametric uncertainty and variability, the seepage evaporation abstraction uses five sets of extracted host-rock thermal-hydrologic-chemical seepage model results to represent the spread of potential seepage and invert imbibition water composition. The selection of five starting waters provides reasonable bounds on the uncertainty and variability in seepage composition (BSC 2004h, Sections 6.9.1 and 8.1). The thermal-hydrologic-chemical seepage model, its uncertainties, and its alternative conceptualizations are discussed in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2004h) and *Abstraction of Drift-Scale Coupled Processes* (BSC 2004i).

The dust deliquescence abstraction does not propagate analytical uncertainties in the concentrations of chemical components of the dust leachate because the effects of these uncertainties are insignificant compared to uncertainties in the geochemical modeling and binning procedures, which are included (BSC 2004f, Section 6.10.3). However, the range of dust leachate compositions represented by the different bins is treated as uncertainty. In any given TSPA-LA realization, the dust bins are probabilistically sampled only once. This approach is conceptually similar to the seepage evaporation abstraction in which the range of starting water compositions is also treated as uncertainty (BSC 2004f, Section 6.15.1.2).

Various degradation modes of the drip shield and waste package have been investigated and documented: for example, *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003e), *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2004j), and *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2004k).

Results of corrosion testing documented in *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003e) show that the titanium drip shield has such corrosion resistance to both general and localized corrosion processes that its barrier function during the regulatory time period is only affected by the possibility of stress corrosion cracking. Such cracks, even if they are initiated and propagate through the titanium alloy, are very tight and do not allow water that may seep on them to penetrate the drip shield or they seal after some time due to the precipitation of dissolved carbonates, sulfates, and other salts. The drip shield by itself reduces the flux that may contact the waste from water seepage.

For the drip shield material, none of the variation in the general corrosion rates determined from the weight-loss measurements of samples exposed at 60°C and 90°C can be attributed to variability (aleatory uncertainty) (BSC 2003e, Section 6.3.4). Therefore, all of the variation in the general corrosion rate is attributed to epistemic uncertainty. In addition, no dependence on temperature was observed over the range of temperatures at which tests were conducted, perhaps because the corrosion rates were so low that measurement uncertainties masked the effect of temperature. Therefore, the general corrosion model developed for the drip shield material has no temperature dependence (a potential source of variability). General corrosion rate distributions were developed from these measured data and used in TSPA-LA to model general corrosion of the drip shield.

The uncertainty treatment of general corrosion rates for the waste package outer barrier material is based on analysis of weight-loss measurements of samples with creviced and weight-loss geometry at temperatures of 60°C and 90°C (BSC 2004j, Section 6.4.3). The majority of the variation (about 97%) in the general corrosion rates used at 60°C determined from the weight-loss measurements is due to variability (aleatory uncertainty). On this basis, the model assigns all of the variation in the general corrosion rates determined from the weight-loss measurements to variability. This assumption is implemented in the TSPA-LA. For use at temperatures other than 60°C, a temperature-dependent general corrosion model was developed for the waste package outer barrier material based on polarization resistance measurements. The temperature-dependence is represented with an Arrhenius temperature term (slope) whose variation is due entirely to epistemic uncertainty.

Alternative conceptual models of general corrosion, including alternative statistical treatment of the data, were investigated in reports generated by the DOE (BSC 2004j, Section 6.4.3.5; BSC 2003e, Section 6.3.6). One alternative conceptual model developed for general corrosion of the waste package outer barrier and drip shield materials (BSC 2004j, Section 6.4.3.5.1; BSC 2003e, Section 6.3.6) is based on the observation that general corrosion rates decrease with time. Use of this model would increase waste package and drip shield lifetimes by a considerable amount. Another alternative conceptual model developed for general corrosion of the waste package outer barrier (BSC 2004j, Section 6.4.3.5.2) involved estimating the effective weight loss of the creviced area (under the crevice former) from the creviced geometry samples. Development of this model used several very conservative assumptions and resulted in a general corrosion rate that was higher than the base-case general corrosion model for the waste package outer barrier. This model is unrealistic and, therefore, not used to support the TSPA-LA model.

Those alternative conceptual models (and alternative statistical representations of the data) that are realistic are also less conservative than the primary model adopted and implemented within the TSPA-LA. In addition, from a risk-based performance perspective, analyses documented in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003f, Section 6.6) show that waste package and drip shield lifetimes are expected to far exceed the 10,000-year regulatory period using the adopted models.

The reports documenting the general corrosion models used for the waste package (BSC 2004j) and drip shield (BSC 2003e) provide sufficient technical basis for the representation of epistemic uncertainty and variability (aleatory uncertainty) in the TSPA-LA model. These uncertainty and variability treatments are adequately implemented within the integrated waste package degradation model, which is a part of the TSPA-LA model.

Uncertainties in data used for localized corrosion modeling of the waste package outer barrier (i.e., crevice repassivation potentials and long-term steady-state corrosion potentials) are characterized, quantified, and propagated through the localized corrosion model abstraction (BSC 2004j, Section 6.4.4). A conservative bounding approach, based on the literature data for similar alloys in highly corrosive environments, captures the uncertainty in the localized corrosion rate of Alloy 22 (BSC 2004j, Section 6.4.4). Microbially influenced corrosion (MIC) data uncertainty is quantified and propagated through the MIC model abstraction (BSC 2004j, Section 6.4.5). Variability in the crevice repassivation potential and corrosion potential among the waste packages is represented with the temporally and spatially varying waste package temperature and water chemistry contacting the waste packages. Uncertainty in the models evaluating localized corrosion of the waste package outer surface is addressed through the qualitative assessment of alternative conceptual models (BSC 2004j, Section 6.4.4).

In addition to corrosion, the waste package degradation during the nominal performance scenario class is affected by the low likelihood of an early waste package failure due to manufacturing defects and the possibility of a deliquescent brine being stable at such high temperatures that it is possible to initiate and propagate localized corrosion processes through the Alloy 22 waste package. These possibilities combine to yield the possible failure degradation of the waste package. Even if the amount of water flow reduction attributed to the drip shield component of the Engineered Barrier System was not considered, the waste package would provide a significant reduction in water contacting waste for commercial spent nuclear fuel, codisposed glass, and DOE spent nuclear fuel.

As discussed in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003f, Section 6.1), the TSPA-LA model propagates uncertainty in waste package degradation through multiple realizations. For each realization, values are sampled for the degradation model parameters to reflect uncertainty in the corrosion behavior. Each realization is a complete simulation of a given number of waste packages, explicitly considering variability in the degradation processes. Accordingly, the model outputs the fraction of the total number of waste packages and drip shields failed versus time. The average number of patch and crack penetrations per failed waste package (or drip shield) are reported as a group of degradation profile curves (resulting from the multiple realizations) that represent the potential range of the output parameters. For example, the waste-package failure time profiles are reported with a group of curves representing the cumulative probability of waste package failures as a function of time. The output is used as input for waste form degradation analysis and radionuclide release analysis from failed waste packages conducted within the TSPA-LA model.

In the TSPA-LA model, cladding degradation is analyzed in two stages: cladding failure and cladding splitting (i.e., cladding axially splits down the length of the fuel rod). Descriptions of the data, models, and relevant uncertainties are located in *Clad Degradation – Summary and Abstraction for LA* (BSC 2003g).

The Zircaloy cladding around the spent nuclear fuel is an extremely corrosion-resistant alloy. Predicted failures are caused by defects in the as-received condition and by damage suffered during a high-magnitude seismic event or a volcanic event, both of which are unlikely. At receipt, about 1% of commercial spent nuclear fuel cladding is predicted to be degraded to such an extent that the cladding is not an effective barrier feature. Therefore, even if the amount of water flow reduction attributed to the drip shield component of the Engineered Barrier System was not considered, the combined effects of the waste packages and cladding would significantly reduce the amount of water contacting the waste in commercial spent nuclear fuel waste packages and codisposed waste packages.

Uncertainties in clad degradation are typically included in the TSPA-LA either through quantified values or through bounding assumptions. The 1% as-received failure rate of commercial spent nuclear fuel cladding reflects the upper limit on the range of possible values and includes the effects of uncertainty (BSC 2003g, Section 6.2.1). While most of the cladding is Zircaloy, a small percentage is composed of stainless steel. Uncertainty in the as-received failure rate is bounded by the assumption that all stainless-steel-clad fuel rods are failed upon receipt and available for instantaneous splitting if the waste package fails (BSC 2003g, Section 6.2.2). In another bounding assumption, fuel rods with failed cladding—either from defects or mechanical damage during a seismic event—are modeled as being instantly split if the waste package fails, leaving the fuel pellets exposed to the waste package internal environment (BSC 2003g, Section 6.2.4).

For the rind calculations, the split in the cladding slowly widens as the UO_2 corrodes because of the increase in volume of the corrosion products. The radionuclides diffuse through the split into the surrounding environment. The uncertainty in rind porosity is included and carried forward to the model abstraction. There is also an uncertainty in UO_2 corrosion rates and chemical and temperature environments inside the waste package. These uncertainties are generated in the TSPA-LA calculations, carried forward into the abstraction, and produce an uncertainty in the rind geometry and diffusion of radionuclides from the fuel rind. The uncertainties in the cladding degradation model are epistemic since they are due to the lack of knowledge (BSC 2003g, Section 6.5). DOE has investigated and documented a variety of alternative conceptual models simulating different aspects of clad degradation (BSC 2003g, Section 6.3).

The data and models used to evaluate waste form degradation are presented in the following reports for three different types of waste forms: *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004l), *Defense HLW Glass Degradation Model* (BSC 2004m), and *DSNF and Other Waste Form Degradation Abstraction* (BSC 2003h). Potential transport of radionuclides through the invert and to the interface between the Engineered Barrier System and the Lower Natural Barrier is described in *EBS Radionuclide Transport Abstraction* (BSC 2003i).

For the Engineered Barrier System, uncertainties in the environmental conditions and the degradation processes are included for the drip shield and waste package performance evaluation, and uncertainties in the degradation and transport processes are included for the waste form, cladding, and invert performance evaluation.

The physical and chemical environment, described previously, affects the degradation rate and characteristics of the waste forms and, more importantly, the solubility of the radionuclides in the aqueous phase, as well as the stability of colloids to which radionuclides may be attached. The rate of release is affected by the advective and diffusive transport pathways out of the waste package and through the invert. In the case of the drip shield remaining intact, the transport pathways through the Engineered Barrier System are diffusive. The solubility limit significantly controls the rate of diffusion as it defines the concentration gradient through which radionuclides may diffuse. Finally, the sorption characteristics of the degraded waste package and internal structural supports affect the release of those radionuclides that are highly sorbed on iron substrates.

Assessment of waste form degradation and radionuclide transport through the invert includes an evaluation of uncertainties in data from tests conducted to measure degradation and transport processes and uncertainties in the conceptual and numerical models used to analyze the processes. These uncertainties are incorporated probabilistically in the performance models by using ranges and distributions of parameter values to describe the physical and chemical environment and the rates of various degradation and transport processes. The ranges of parameters and process rates are based on the results of testing and analysis, as well as on the fundamental physical principles at work. In addition, alternative conceptual models are considered in the treatment of model uncertainty.

LOWER NATURAL BARRIER

The Lower Natural Barrier provides the function of substantially reducing the rate of movement of radionuclides from the repository to the accessible environment. This barrier combines both the unsaturated zone and saturated zone features and groundwater flow and radionuclide transport processes to evaluate release rates for radionuclides.

The unsaturated zone below the repository impedes the movement of radionuclides from the repository horizon to the water table. As water percolates down, sorption, colloid filtration, and matrix diffusion cause the movement of radionuclides to be slower relative to the general movement of the percolating water. Radionuclides are also dispersed during this movement because of variability in radionuclide transport times and in the retardation characteristics of the various volcanic units.

The saturated zone of the Lower Natural Barrier includes the fractured volcanic rocks from below the repository and the saturated alluvium at the water table from the volcanic aquifer to the accessible environment. The movement of radionuclides in the saturated zone is slow because the velocity of water that can carry them is low. In addition, several processes cause the movement of radionuclides to be slower compared to the rate of movement of the water.

Flow in the upper and lower volcanic aquifers is predominantly in the fractures. Because the matrix materials of the volcanic tuffs have lower hydraulic conductivity than that observed in flowing fractures under natural groundwater-flow conditions and also have higher effective porosity as fractures, there is a correspondingly greater volume of fluid stored in the matrix pore space of these saturated aquifers. The additional stored fluid and pore space is important to radionuclide transport because radionuclides can exchange between the fractures and matrix via matrix diffusion. This diffusive exchange results in a slower effective travel velocity for the bulk of the released radionuclides relative to water-flow velocities in the fractures because the velocity of water in the pores of the matrix is slower than that in the fracture pores, and sorption onto mineral surface areas in the matrix pores results in even slower movement of the radionuclides that diffuse into the matrix materials.

Because the alluvial materials are a porous media with few connected fracture pathways, water flow and radionuclide transport occur in intergranular pores. The conceptual model for transport in the alluvial sediments is that of a porous continuum. The effective porosity of the alluvium is greater than the fracture porosity of the tuffs. Consequently, pore velocities in the alluvium are smaller than those in the fractures of the volcanic aquifers. Although matrix diffusion is not considered to be important in the alluvium, radionuclide movement is slow because of the low water velocity. In addition, sorption onto minerals in the alluvium results in retardation of the radionuclide movement relative to the water movement in these sediments.

The volcanic rocks and alluvial material in the saturated zone also reduce the movement of radionuclides associated with colloids. Filtration of colloids results in retardation of the movement of radionuclides embedded in the colloids or that are irreversibly sorbed to these colloids. Radionuclides that are sorbed reversibly to colloids are affected by matrix diffusion in the volcanic aquifers and by sorption in the alluvial sediments; consequently, movement of these colloid-associated radionuclides is also retarded relative to the movement of water in the saturated zone.

The combination of low groundwater velocity and processes that reduce the release of radionuclides relative to water flow results in a capability to substantially reduce the movement of radionuclides to the accessible environment.

For the Lower Natural Barrier, uncertainties are a function of the applicability of the numerical and conceptual models (BSC 2003j, Section 8.3.2) used to describe flow and transport and of the degree of knowledge of the characteristics of the Yucca Mountain site. To accommodate both variability and uncertainty in the description of the site, many of the input parameters to the unsaturated zone transport model are defined as probabilistic distributions (BSC 2003j). The variability and uncertainty in barrier capability is reflected in the range of transport times and radionuclide breakthrough curves that result from the model. The model projections are calibrated and compared to geologic data (e.g., the groundwater chemistry and ages) and other analog information to ensure that results are consistent with the known characteristics of the unsaturated zone flow system in the vicinity of Yucca Mountain.

The model for unsaturated zone transport (BSC 2003j) explicitly accounts for uncertainties associated with the following:

- Fracture flow in the vitric CHn unit (e.g., BSC 2003j, Section 6.6.3)
- Diversion of groundwater flow away from the zeolitic CHn unit (e.g., BSC 2003j, Section 6.7.2)
- Fracture–matrix interaction along flow paths in fracture systems within the TSw unit (e.g., BSC 2003j, Section 6.7.2)
- The extrapolation of hydrogeologic properties for the fault intervals in the CHn unit and the Crater Flat undifferentiated hydrogeologic unit based on data collected for faults in the TSw unit (e.g., BSC 2003j, Section 6.10.1).

Uncertainties in saturated zone groundwater flow and transport have been addressed by using probabilistic representations of parameter values that are important to transport, such as hydraulic and geologic properties (BSC 2004n; BSC 2004o). Uncertainties have also been evaluated considering a base case with a mean flux of 0.6 m/yr, a low case with a flux a factor of 30 lower, and a high case with a flux a factor of 10 higher. Uncertainty in the direction of groundwater flow has been considered by evaluating groundwater flow fields with and without horizontal anisotropy in permeability. The result of considering both types of uncertainty is six alternative groundwater flow fields.

There is uncertainty concerning the nature of the geology in the saturated zone along the inferred flow path from the repository at distances of approximately 10 to 18 km downgradient from the repository (BSC 2004n; BSC 2004o). The portions of the flow path devoted to fractured volcanic rock and alluvium are important to saturated zone barrier capability because the movement of radionuclides through this barrier is affected by the contrast in the flow between these two units and because the retardation characteristics of the two units are different. Uncertainty in the location of the alluvium is represented in terms of a probability distribution. This distribution is sampled in the TSPA-LA analyses.

The information in this enclosure is responsive to agreement TSPAI 1.02 made between DOE and NRC. This enclosure contains the information that DOE considers necessary for NRC review for closure of this agreement.

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BSC 2003e. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030626.0001.

BSC 2003f. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031208.0004.

BSC 2003g. *Clad Degradation – Summary and Abstraction for LA.* ANL-WIS-MD-000021 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030626.0002.

BSC 2003h. *DSNF and Other Waste Form Degradation Abstraction.* ANL-WIS-MD-000004 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030711.0002.

BSC 2003i. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 01F. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20031210.0361.

BSC 2003j. *Radionuclide Transport Models Under Ambient Conditions.* MDL-NBS-HS-000008 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031201.0002.

BSC 2004a. *UZ Flow Models and Submodels.* MDL-NBS-HS-000006 REV 01 ICN 01A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20040126.0082.

BSC 2004b. *Seepage Calibration Model and Seepage Testing Data.* MDL-NBS-HS-000004 REV 02, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030408.0004; DOC.20040202.0003; DOC.20040219.0003.

BSC 2004c. *Abstraction of Drift Seepage.* MDL-NBS-HS-000019 REV 00 ICN 01, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031112.0002; DOC.20040223.0001.

BSC 2004d. *Seepage Model for PA Including Drift Collapse.* MDL-NBS-HS-000002 REV 02, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030709.0001; DOC.20040512.0002; DOC.20040615.0004.

BSC 2004e. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040301.0004.

BSC 2004f. *Engineered Barrier System: Physical and Chemical Environment Model.* ANL-EBS-MD-000033 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040212.0004.

BSC 2004g. *In-Drift Precipitates/Salts Model.* ANL-EBS-MD-000045 REV 01 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040202.0001.

BSC 2004h. *Drift-Scale Coupled Processes (DST and THC Seepage) Models.* MDL-NBS-HS-000001 REV 02, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030804.0004; DOC.20040219.0002; DOC.20040405.0005.

BSC 2004i. *Abstraction of Drift-Scale Coupled Processes.* MDL-NBS-HS-000018 REV 00, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031223.0004; DOC.20040223.0003; DOC.20040512.0001.

BSC 2004j. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier.* ANL-EBS-MD-000003 REV 02A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20040811.0161.

BSC 2004k. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material.* ANL-EBS-MD-000005 REV 01 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040318.0010.

BSC 2004l. *CSNF Waste Form Degradation: Summary Abstraction.* ANL-EBS-MD-000015 REV 01, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030708.0004; DOC.20031224.0001; DOC.20040202.0002.

BSC 2004m. *Defense HLW Glass Degradation Model.* ANL-EBS-MD-000016 REV 01 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040223.0006.

BSC 2004n. *Site Scale Saturated Zone Flow Model.* MDL-NBS-HS-000011 REV 01, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040126.0004; DOC.20040415.0001.

BSC 2004o. *Site-Scale Saturated Zone Transport.* MDL-NBS-HS-000010 REV 01, with errata. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040126.0003; DOC.20040325.0001; DOC.20040412.0007.

Reamer, C.W. 2001. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6 through 10, 2001)." Letter from C.W. Reamer (NRC) to S. Brocoum (DOE/YMSCO), August 23, 2001, with enclosure. ACC: MOL.20011029.0281.

ENCLOSURE 2

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (RESPONSE TO TSPAI 3.37)

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application as the approved analyses of record at the time of License Application submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the License Application.

ENCLOSURE 2

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (RESPONSE TO TSPAI 3.37)

BACKGROUND

Agreement was reached for Total System Performance Assessment and Integration (TSPAI) 3.37 during the Technical Exchange and Management Meeting on Total System Performance and Integration held August 6 through 10, 2001, in Las Vegas, Nevada. The NRC documented the agreement in a letter dated August 23, 2001 (Reamer 2001).

The U.S. Department of Energy (DOE) transmitted a report entitled *Response to TSPAI 3.37, Adequacy of the BDCF Sampling Method and Correlation* to satisfy the KTI agreement in a letter dated August 29, 2002 (Ziegler 2002).

The NRC responded to DOE and provided their assessment of the report in a letter dated February 5, 2003 (Schlueter 2003). NRC determined the report did not meet the intent of the agreement in that the report appeared to attempt to justify the approach used in the TSPA-SR and not the approach the DOE would use in the license application; and the reasoned arguments and theoretical statistical analyses provided were not sufficient to indicate that the sampling method in the TSPA-LA adequately represents the uncertainty, variability, and correlations for the biosphere process model.

Additionally, NRC provided items DOE should consider in the development of its justification for the approach to uncertainty and variability for the biosphere.

The considerations are:

1. Any selected approach by DOE should be consistent with the overall approach to uncertainty and variability for the compliance demonstration (i.e., the "Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application").

2. A quantitative analysis should be used to support the justification of the selected approach. Possible quantitative analyses could include (1) comparing the expected doses calculated from the biosphere dose conversion factors (BDCFs) from the original stochastic modeling with the expected doses from the selected approach, or (2) ancillary analyses showing stability in the mean dose to support the claim DOE is using a sufficiently large number of samples. If theoretical arguments are used, sufficient information should be provided to show the theoretical basis holds for the approach used in the TSPA-LA.

3. DOE asserts that the TSPA-SR approach is conservative, because the approach results in an increased variance of the calculated dose distribution. Because compliance with the postclosure public health and environment standards is based on the mean of the

> distribution of projected doses (see 10 CFR 63.303), the claim that the approach is conservative as a consequence of this increased variance does not appear to be sufficiently justified. For example, the response demonstrates that the sampling approach does not affect the mean of the dose distribution if enough samples are taken, so the approach would not be conservative with respect to the mean.

The wording of the agreement is as follows:

TSPAI 3.37

> Provide a quantitative analysis that the sampling method including the correlations to NP used by the TSPA code to abstract the GENII-S process model code adequately represent the uncertainty and variability and correlations for the biosphere process model (DOSE3.4.1).
>
> DOE will provide a quantitative analysis that the sampling method including the correlations between BDCFs utilized by the TSPA code to abstract the GENII-S process model data adequately represent the uncertainty and variability and correlations for the biosphere process model. This will be documented in Nominal Performance Biosphere Dose Conversion Factor Analysis AMR (ANL-MGR-MD-000009), Disruptive Event Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000003) or other document expected to be available to NRC in FY 2003. Results of these analyses will be documented in the TSPA for any potential license application expected to be available to NRC in FY 2003.

RESPONSE

The DOE has developed the Environmental Radiation Model for Yucca Mountain Nevada (ERMYN) to replace the GENII-S code previously used for biosphere modeling. ERMYN is described in *Biosphere Model Report* (BSC 2003a). ERMYN models radionuclide transport processes in the biosphere and the associated human exposure that may result from radionuclide transport from the repository to the accessible environment.

The model is consistent with the overall approach to uncertainty and variability as described in the "Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application."

A quantitative analysis is not necessary because DOE no longer correlates or abstracts the results of the biosphere model.

The results of the analyses are in the TSPA-LA, which will be available at license application.

BASIS FOR THE RESPONSE

The primary output of the ERMYN is BDCFs, which are equivalent to the annual, all-pathway dose that the receptor would experience as a result of a unit activity concentration of a radionuclide in groundwater or volcanic ash. BDCFs are used in the TSPA-LA model to calculate the pathway annual doses for a given predicted concentration of radionuclides in groundwater or volcanic ash. *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003b) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003c) document the generation of the BDCFs for input into the TSPA-LA.

The BDCFs were calculated for each of the radionuclides of interest in a series of biosphere model realizations using a probabilistic approach that allows statistical sampling of parameter values defined by their probability distribution functions. Each simulation resulted in 1,000 model realizations. For the groundwater exposure scenario, separate simulations were run to calculate BDCFs for the three climate states considered in the TSPA-LA: the modern climate, the monsoon climate, and the glacial-transition climate. For the disruptive events scenario, one set of BDCFs was developed for all climate states.

Each set of BDCFs is in the format of 1,000 row vectors (one row vector for each model realization). Row vectors contain the results of individual model realizations, with the vector elements being the BDCF for a radionuclide for a realization. A BDCF vector can be regarded as a one-dimensional array containing the results of a single realization of the biosphere model for all radionuclides of interest. BDCFs in a given vector (i.e., for a given model realization) were calculated using the same radionuclide-independent input parameter values, thereby capturing the inherent correlation in BDCFs among radionuclides.

The set of 1,000 row vectors was sampled randomly within the TSPA-LA code to propagate uncertainty from the biosphere model into the TSPA-LA dose calculations. This approach retains the correct correlation among the BDCFs of all radionuclides and eliminates the sampling and correlation concerns raised by the NRC in its evaluations of the TSPA-SR biosphere abstraction process.

A quantitative analysis is not necessary because DOE no longer correlates or abstracts results of the biosphere model.

The use of ERMYN to calculate BDCFs for unit activity concentration of a radionuclide in groundwater or volcanic ash supports that the TSPA-LA approach will be conservative.

The information in this enclosure is responsive to agreement TSPAI 3.37 made between DOE and NRC. This enclosure contains the information that DOE considers necessary for NRC review for closure of this agreement.

REFERENCES

Documents Cited

BSC (Bechtel SAIC Company) 2003a. *Biosphere Model Report.* MDL-MGR-MD-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030721.0001; DOC.20031014.0002; DOC.20031028.0001.

BSC 2003b. *Nominal Performance Biosphere Dose Conversion Factor Analysis.* ANL-MGR-MD-000009 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030728.0008.

BSC 2003c. *Disruptive Event Biosphere Dose Conversion Factor Analysis.* ANL-MGR-MD-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030724.0003.

Reamer, C.W. 2001. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6 through 10, 2001)." Letter from C.W. Reamer (NRC) to S. Brocoum (DOE/YMSCO), August 23, 2001, with enclosure. ACC: MOL.20011029.0281.

Schlueter, J.R. 2003. "Total System Performance Assessment and Integration Agreement 3.37: The Information Provided Was Not Responsive to the Agreement, so the Agreement Is Still Characterized as "Not Received." Letter from J.R. Schlueter (NRC) to J.D. Ziegler (DOE), February 5, 2003, with enclosure. ACC: MOL.20030905.0151.

Ziegler, J.D. 2002. "Transmittal of Report Addressing Key Technical Issue (KTI) Agreement Item Total System Performance Assessment and Integration (TSPAI) 3.37." Letter from J.D. Ziegler (DOE) to J.R. Schlueter (NRC), August 29, 2002, OL&RC:TCG-1671, with enclosure. ACC: MOL.20021022.0274.

Codes, Standards, and Regulations

10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

ENCLOSURE 3

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENTS FOR TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI) 3.38 AIN-1, 3.39 AIN-1, 3.41 AIN-1, 4.01 AIN-1, AND GEN 1.01 (COMMENTS 78 AND 96)

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application as the approved analyses of record at the time of License Application submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the License Application.

ENCLOSURE 3

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENTS FOR TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI), 3.38 AIN-1, 3.39 AIN-1, 3.41 AIN-1, 4.01 AIN-1, AND GEN 1.01 (COMMENTS 78 AND 96)

BACKGROUND

Agreements were reached for TSPAI 3.38, TSPAI 3.39, TSPAI 3.41, and TSPAI 4.01 during the Technical Exchange and Management Meeting on Total System Performance and Integration held August 6 through 10, 2001 in Las Vegas, Nevada. The U.S. Nuclear Regulatory Commission (NRC) documented the agreements in a letter dated August 23, 2001 (Reamer 2001).

The U.S. Department of Energy (DOE) provided *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002) to address KTI agreements for TSPAI 3.38, 3.39, 3.41, and 4.01 in a letter to the NRC dated May 9, 2002 (Ziegler 2002).

In the transmittal letter, DOE requested that the NRC consider closing KTI agreements TSPAI 3.38, 3.39, 3.41, and 4.01, as *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002) addresses the approach for consistent treatment of alternative conceptual models, model abstractions, and parameter uncertainty to be used in the development of inputs for and use of the TSPA model, and the document provides a supplemental level of detail useful for implementation of procedure AP-SIII.10Q, *Models*, which governs the preparation of model reports, including model abstractions.

NRC responded to DOE in a letter dated October 11, 2002, summarizing its review of the information provided. NRC determined that additional information would be needed to address TSPAI 3.38, 3.39, 3.41, and 4.01(Schlueter 2002).

NRC also concluded that it was premature to characterize these agreements as complete because there was no objective evidence of the successful implementation of the guidelines and the guidelines do not embody the same gravity as do quality assurance procedural requirements, in which case audits are conducted to evaluate adherence to the procedures.

GEN 1.01 (Comments 78 and 96) were discussed with DOE, and DOE provided initial responses during a Technical Exchange and Management Meeting on Range of Thermal Operating Temperatures held on September 18 and 19, 2001 (Reamer and Gil 2001). GEN 1.01 (Comment 78) is presented with TSPAI 3.38 AIN-1 and GEN 1.01 (Comment 96) is presented with TSPAI 4.01 AIN-1.

The wording of the agreements and GEN 1.01 (Comments 78 and 96) are as follows:

TSPAI 3.38[1]

DOE will develop guidance in the model abstraction process that can be adhered to by all model developers so that (1) the abstraction process, (2) the selection of conservatism in components, and (3) representation of uncertainty are systematic across the TSPA model. DOE will evaluate and define approaches to deal with: (1) evaluating non-linear models as to what their most conservative settings may be if conservatism is being used to address uncertainty, and (2) trying to utilize human intuition in a complex system. In addition, DOE will consider adding these items to the internal/external reviewer's checklists to ensure proper implementation of the improved methodology (TSPA0002).

DOE will develop written guidance in the model abstraction process for model developers so that (1) the abstraction process, (2) the selection of conservatism in components, and (3) representation of uncertainty, are systematic across the TSPA model. These guidelines will address: (1) evaluation of non-linear models when conservatism is being utilized to address uncertainty, and (2) utilization of decisions based on technical judgement in a complex system. These guidelines will be developed, implemented and be made available to the NRC in FY 2002.

TSPAI 3.38 AIN–1

DOE should provide a description of the approach used to evaluate the appropriateness of technical-judgment-based conservative selections, with respect to complex and non-linear models, and how the resulting decisions would be documented.

GEN 1.01 Comment 78[2]

Page 3-6: "Uncertainties are addressed by bounding and sensitivity studies as discussed in DOE 2001…" Sensitivity studies can be an effective mechanism to assess uncertainties, however if the uncertainties show up as contributing to the output then they must be represented in the abstraction to the TSPA.

Initial Response to Comment 78 (from September 18 to 19, 2001, meeting)

DOE acknowledges this concern, and will address specific, relevant issues according to KTI agreement TSPAI 3.38.[2]

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[1]TSPA0002 in this agreement refers to Total System Performance Assessment and Integration, Subissue 3, Methodology of Model Abstraction (BSC 2001a, p. MA-135). This item addresses the NRC's concern regarding the use of appropriate methodology for model abstraction simplifications and selection of conservative parameter distributions, conceptual models, or modeling approaches.

[2]The specific page number referral cited below is from *FY01 Supplemental Science and Performance Analyses, Volume 1: Scientific Bases and Analyses* (BSC 2001b).

TSPAI 3.39[3]

In future performance assessments, DOE should document the simplifications used for abstractions per TSPAI 3.38 activities. Justification will be provided to show that the simplifications appropriately represent the necessary processes and appropriately propagate process model uncertainties. Comparisons of output from process models to performance assessment abstractions will be provided, with the level of detail in the comparisons commensurate with any reduction in propagated uncertainty and the risk significance of the model (TSPA0003).

DOE will document the simplifications utilized for abstractions per TSPAI 3.38 activities for all future performance assessments. Justification will be provided to show that the simplifications appropriately represent the necessary processes and appropriately propagate process model uncertainties. Comparisons of output from process models to performance assessment abstractions will be provided, with the level of detail in the comparisons commensurate with any reduction in propagated uncertainty and the risk significance of the model. The documentation of the information will be provided in abstraction AMRs in FY 2003.

TSPAI 3.39 AIN-1

NRC Review: The NRC staff has decided that it is premature to characterize TSPAI Agreement 3.39 as complete solely on the basis of the Guidelines provided by DOE. It is premature because: (1) there is no objective evidence of the successful implementation of the Guidelines and (2) the Guidelines do not embody the same gravity as do quality assurance procedural requirements, where audits are conducted to evaluate adherence to the procedures.

Additional Information Needed: The information requested in TSPAI Agreement 3.39 needs to be addressed.

TSPAI 3.41

To provide support for the mathematical representation of data uncertainty in the TSPA, the DOE will provide technical basis for the data distributions used in the TSPA. An example of how this may be accomplished is the representation on a figure or chart of the data plotted as an empirical distribution and the probability distribution assigned to fit these data.

DOE will provide the technical basis for the data distributions utilized in the TSPA to provide support for the mathematical representation of data uncertainty in the TSPA. The documentation of the technical basis will be incorporated in documentation associated with TSPA for any potential license application. The documentation is expected to be available to NRC in FY 2003.

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[3]TSPA0003 in this agreement refers to Total System Performance Assessment and Integration, Subissue 3, Model Abstraction Simplification (BSC 2001a, p. MA-141). This item addresses the NRC's concern regarding the basis for model abstraction simplifications.

TSPAI 3.41 AIN-1

In addition to the information that DOE has already acknowledged that it needs to provide in response to this agreement (i.e., documentation, justification, and comparisons that are to be provided in the model reports), the following information is needed from DOE.

1. Justification that the DOE's use of the information entropy approach is appropriate, when used to develop the expected annual dose to the reasonably maximally exposed individual and demonstration of compliance with the groundwater concentration limits should be provided.

2. The approach that DOE will use to address variability, specifically, the lumping (smoothing) of variability, when parameters are defined, should be provided.

TSPAI 4.01

DOE will document the methodology that will be used to incorporate alternative conceptual models into the performance assessment. The methodology will ensure that the representation of alternative conceptual models in the TSPA does not result in an underestimation of risk. DOE will document the guidance given to process-level experts for the treatment of alternative models. The implementation of the methodology will be sufficient to allow a clear understanding of the potential effect of alternative conceptual models and their associated uncertainties on the performance assessment. The methodology will be documented in the TSPA-LA methods and assumptions document in FY02. The results will be documented in the appropriate AMRs or the TSPA for any potential license application in FY 2003.

TSPAI 4.01 AIN-1

1) Clarification of DOE’s use of reasonableness (see, for example, page 13 of the Guidelines) and/or additional justification for the criteria that alternative conceptual model must be “reasonable” as used in Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis,” should be provided.

2) Clarification of how DOE intends to apply its criterion on consistency with available data and scientific understanding. If the absence of validation information (e.g., data) is used to reject an alternative conceptual model, this approach and subsequent decisions where this is done should be documented and justified.

3) Clarification of DOE’s approach to documenting the effects of alternative conceptual models and how it will be sufficient to allow a clear understanding of the potential effects of alternative conceptual models and

their uncertainty on the performance assessment. This clarification should include DOE's approach to presenting dis-aggregated results of alternative conceptual models.

4) Clarification of how DOE's approach—which, according to the Guidelines, involves weighting alternative conceptual models—will avoid underestimating the risk when the results are presented.

5) Clarification of its approach to using sensitive or key parameters from previous analyses when evaluating potential future alternative conceptual models. If DOE intends to use a threshold for discriminating these parameters from others, this should be expressed.

6) Clarification of the guidance that will be given to the model developers that would provide consistency in the development of model validation criteria, such that the representation of uncertainty is systematic throughout the performance assessment.

GEN 1.01 (Comment 96)[4]

Page 4-56: The analytical work is an excellent example of alternative methods that can be pursued as multiple lines of evidence. However, in this case it does raise additional technical questions. For example, would the chemistry of the solution in the above boiling region influence the behavior? In particular, if the solution were a chloride-brine would it have different physical characteristics than dilute water? Secondly, if 15% of the realizations predicted penetration, then roughly 1600+ waste packages (on average) should experience these conditions. Finally, where is the support for the original modeling result if the analytical result contradicts the conclusions made with the original model? Page 4-57 describes "more extreme conditions", but it was not obvious that the conditions were more extreme in the analytical work, rather it appeared that the analytical work evaluated processes on a scale that the numerical model can not evaluate.

Initial Response to Comment 96 (from September 18 to 19, 2001, meeting)

Although the asperity-induced episodic infiltration model provides convenient analytical expressions for the episodicity and water-penetration distances, it also includes a number of important assumptions (consistent with KTI agreement TSPAI 4.01):

Although the configuration of the infiltrating weeps is three-dimensional, the flow of water through the fractures is modeled as one-dimensional in the downward direction. Water accumulation and drainage is governed by a weep width that constrains the physical boundaries of accumulation and drainage in the lateral direction.

[4]The specific page number referrals cited below is from *FY01 Supplemental Science and Performance Analyses, Volume 1: Scientific Bases and Analyses* (BSC 2001b).

> All fluid and material properties are modeled as constant over time. In the application presented here, properties were averaged over temperature ranges from ambient (20°C) to boiling (96°C for Yucca Mountain). Distributions were obtained from previous Yucca Mountain reports, as summarized in Table 4.3.5-3.
>
> Fracture-matrix interaction (e.g., imbibition) is ignored in this analysis. If a significant amount of matrix imbibition exists, the water-penetration distance into the superheated distance will be less.

RESPONSE

DOE has developed guidance that addresses the issues raised in KTI agreements and associated Additional Information Needed (AIN) requests TSPAI 3.38, 3.38 AIN-1, 3.39, 3.39 AIN-1, 3.41, 3.41 AIN-1, 4.01, 4.01 AIN-1, and has confidence that this guidance addresses the concerns discussed in the KTI agreements and AINs (i.e., the abstraction process, selection of conservatism in components, systematic representation of uncertainty across the TSPA model, etc.) and has been implemented by the model developers The TSPA-LA describes how these were implemented. The TSPA-LA will be available at license application.

Responses for the specific issues raised in GEN 1.01 (Comments 78 and 96) are presented after the basis for the response to the KTI agreements and associated AINs.

BASIS FOR THE RESPONSE

Guidance to Technical Staff–DOE provided guidance in a number of documents and made procedural revisions to address these agreements. Project technical staff were provided with specific criteria to ensure consistent treatment of alternative conceptual models, model abstractions, and parameter uncertainty. The documents include *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002); and *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003).

These documents were provided to project staff as guides for the development of reports supporting the TSPA-LA. These documents address the abstraction process, the selection of conservatism in components, and the representation of uncertainty, including the use of alternative conceptual models. The guidelines describe DOE's approach to the abstraction process and the methodology for representation of uncertainty in a systematic fashion, and were applied systematically across the TSPA-LA model. *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002); and *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003) were developed so that when fully implemented, they would result in greater transparency and consistency of various aspects of the model and abstraction process.

AP-SIII.10Q, *Models*, and AP-SIII.9Q, *Scientific Analyses*, are the procedures for developing and validating models and conducting analyses, and have had a number of revisions to clarify requirements for model and analysis reports. The procedures require a description of uncertainties and sources of uncertainties, discussion of the impacts of uncertainties on outputs, as well as discussions of sensitivities and results of calibration activities in the case of newly developed models. AP-SIII.10Q also requires that results of abstraction models be compared to results of the underlying process model for purposes of model validation, which results in a consideration of the propagation of uncertainty from the process level to the abstraction.

During 2003, as the suite of scientific analyses and model reports supporting the TSPA-LA were developed (or revised), performance assessment management reviews (Table 1, management review type) were conducted to evaluate the technical adequacy, completeness, and quality of the information for the intended use in the TSPA-LA model development. The objective of these reviews was to ensure the consistency of the products that support the TSPA-LA and to elevate and resolve any differences in approach or methodology that could affect the suitability of the abstraction and other model or analysis outputs for development of the TSPA-LA. These assessments consisted of two levels of review. The first review was to ensure consistency of the products that support TSPA-LA and to elevate and resolve any differences in approach or methodology that may effect the suitability of the output. This review was performed by the abstraction team lead, parameter team lead, and the FEPs team lead (BSC 2003). The purpose of the second review was to assess the technical information available at the time, and to identify areas where additional clarification or information was believed necessary to improve the final quality of the outputs to the TSPA-LA. This review was conducted by an integrated team of BSC and DOE management, as well as technical experts in appropriate areas, and resulted in reprioritization of work efforts, and in some cases, new work scope was determined to be necessary.

Table 1. Audits, Surveillances, Assessments, and Management Reviews

Type	Number	Date
Audit	ORCWM-BSC-04-01	11/17-24/2003
Audit	ORCWM-LLNL-04-07	4/19-23/2004
Audit	OQAP-BSC-03-05	3/17-27/2003
Audit	OQAC-BSC-03-04	3/24-27/2003
Audit	OQAP-BSC-03-07	6/3-13/2003
Audit	OQAP-BSC-03-14	9/8-19/2003
Audit	OQAC-BSC-03-13	9/22-26/2003
Audit	OQAP-BSC-03-10	10/21-31/2003
Audit	BQAP-BSC-03-02	11/12-20/2003
Audit	BQAC-BSC-03-12	4/7-11/2003
Audit	BQAC-USGS-03-13	5/12-16/2003
Audit	BQAC-LANL-03-08	5/19-22/2003
Audit	BQAC-LBNL-03-14	7/14-18/2003
Audit	BQAC-SNL-03-16	7/22-25/2003
Audit	BSC-ARC-02-05	3/5-8/2002
Audit	BSC-ARC-02-011	6/17-21/2002

Table 1. Audits, Surveillances, Assessments, and Management Reviews (Continued)

Type	Number	Date
Surveillance	BQA-SI-04-002	1/28-2/13/2004
Surveillance	BQA-SI-04-036	2/18-3/15/2004
Surveillance	BQA-SI-04-043	1/17/03-1/12/04
Surveillance	BQA-SI-04-048	1/12-2/27/2004
Surveillance	BQA-SI-04-061	3/9/2004
Surveillance	BQA-SI-04-064	3/1-12/2004
Surveillance	BQA-SI-03-092	4/18-28/2003
Surveillance	BQA-SI-03-094	8/4-11/2003
Surveillance	BQA-SI-03-115	8/19-20/2003
Surveillance	BQA-SI-03-131	9/8-19/2003
Surveillance	BQA-SE-03-129	9/23-24/2003
Surveillance	OQA-SE-03-003	11/11-13-2002
Surveillance	OQA-SI-03-004	10/14-11/22/2002
Surveillance	OQA-SE-03-009	12/9-11/2002
Surveillance	BSC-02-S-05	1/8-10/2002
Surveillance	BSC-02-S-09	2/19-21/2002
QA Assessment	SA-QE-2004-002	12/3/2003-1/6/2004
Mgt. Assessment	SA-PAP-2003-007	10/16-24/2002
Mgt. Assessment	SA-ENG-2002-006	7/15-9/16/2002
CSO Assessment	SA-CSO/LBNL-2003-001	10/3-29/2002
CSO Assessment	SA-CSO-2003-004	1/19-4/14/2003
CSO Assessment	SA-CSO-2003-001	1/19-24/2003
CSO Assessment	SA-CSO-2003-005	7/21-8/21/2003
CSO Assessment	SA-CSO/LBNL-2003-003	7/11-13/2003
Mgmt. Review	SA-PA-2003-015	12/1/02-1/29/03
Mgmt. Review	SA-PA-2003-017	1/15 – 2/19/03
Mgmt. Review	SA-PA-2003-021	2/1-3/31/03
Mgmt. Review	NA	7/2003
Mgmt. Review	NA	8/2003
Mgmt. Review	NA	8/2003

Status of Implementation of Guidance–The status of implementation of *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002)); and *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003), and the revised procedures for model and scientific analysis development are evaluated in a number of ways and is an ongoing process. Monthly performance measurements against established metrics provides a source of information for certain aspects of this information. These sources are particularly useful for easily quantified information, such as the number and severity of quality assurance findings, as well as human performance.

Ongoing and special activities that provide status information include quality assurance audits and surveillances, self-assessments, management assessments, and formal peer reviews. Some of these activities occur in-process and provide the opportunity for management to intervene and focus attention on areas needing improvement. Carefully planned self-assessments and management assessments provide useful information that allows managers and supervisors to determine if previous guidance provided in *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002), in *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003), and through enhancements to implementing procedures, is effective

Quality assurance audits and surveillances (Table 1) have been performed on the implementing procedures referenced in *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002) that address model development and documentation, specifically, AP-2.27Q, *Planning for Science Activities*; AP-SIII.10Q, *Models;* and AP-SIII.9Q, *Scientific Analyses*. For the fiscal years 2002, 2003, and 2004, a total of 16 audits and 16 surveillances have been performed that included evaluation of these implementing procedures in their scope. Deficiencies noted during the performance of the audit, surveillance, or assessment were entered in the appropriate corrective action program for resolution. Although implementation of requirements for model validation in AP-SIII.10Q has resulted in periodic identification of implementation problems, the procedures have been found to be effective and contain adequate flowdown of requirements from the *Quality Assurance Requirements Description* (DOE 2004). A number of specific actions to improve human performance relative to model validation have been taken as a result of continued identification of issues. For example, requirements for prejob briefings at key process steps have been added to the key procedures.

A self-assessment, conducted by quality assurance staff (Table 1, quality assurance assessment type), reviewed condition reports related to model validation issues to determine if upgrades to procedures AP-2.27Q, *Planning for Science Activities*, and AP-SIII.10Q, *Models*, were needed to improve the clarity of the procedures to address identified implementation problems. Several Level D condition reports (opportunities for improvement) were issued as a result of this self-assessment.

Two management self-assessments (Table 1, management assessment type) were performed; these assessments examined planning and implementation of the procedures for analyses and models.

In addition, five self-assessments (Table 1, CSO assessment type) covering various specific model reports were conducted under the cognizance of the Chief Science Officer in accordance with procedure AP-2.20Q, *Self-Assessments*. These assessments evaluated model development and validation as it occurred, as well as determining if problems identified through the corrective action program, technical error reports, and audits have been incorporated in the appropriate reports. The overall purpose of these self-assessments was to ensure that the Chief Science Officer's role as an in-process model validation check was being effectively implemented.

As one of the options chosen for postdevelopment validation of the TSPA-LA model report, an independent technical review was conducted in accordance with *Technical Work Plan for: TSPA-LA Model Development, Initial Use, and Documentation* (BSC 2004a). The review team consisted of several qualified off-project consultants. The reviewers were senior scientists and engineers with training and experience in the implementation of performance assessment methodology for complex systems related to nuclear waste repository licensing and development, as well as the use of complex models related to waste isolation and containment. The team has reviewed the TSPA-LA model according to specific criteria to provide a thorough evaluation of the TSPA-LA and its supporting documentation, and to support the validation of the TSPA-LA for use in regulatory decision making, according to AP-SIII.10Q (BSC 2004a).

The quality assurance audits, surveillances, self-assessments, management assessments and reviews (Table 1), and peer reviews demonstrate reasonable assurance that *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* (BSC 2002) and implementing procedures have been adequately constituted and implemented, that these guidelines achieved the general level of rigor indicated by the NRC's issues, and that when discrepancies were identified, they were properly dispositioned.

Regulatory Integration Team–Another step was taken by DOE to ensure that scientific analyses and model reports supporting the TSPA-LA were integrated and transparent, and consistent with previous guidance. To accomplish this, DOE formed the regulatory integration team, comprised of approximately 150 technical staff who performed detailed reviews of the scientific analyses and model reports. These reviews were performed in accordance with *Technical Work Plan for Regulatory Integration Evaluation of Analysis and Model Reports Supporting the TSPA-LA* (BSC 2004b). The reviews represent a comprehensive evaluation by the following teams: integration; parameters; features, events, and processes; and five teams representing analysis/model topical areas (natural systems, environment, engineered systems, seismic, and igneous). Individuals experienced in developing nuclear safety related analyses and related documentation were assigned to each of the five topical analysis/model teams to conduct evaluations of the reports for purposes of transparency, traceability, and adequacy for use in the licensing environment.

The regulatory integration teams developed the following products:

- Checklists for each assigned scientific analysis, model report, or engineering calculation (where these documents provided inputs to model or analyses reports), prepared by the analysis/model teams

- Similar materials documenting the parameter traces from TSPA-LA to model and analysis reports, and FEP consistency evaluations performed by the parameter team and FEPs team, respectively

- Summaries from each contributing team listing evaluation findings in sufficient detail, referencing specific analysis or model reports in order to support prioritization of evaluation findings and decisions as to what further remedial work may be needed (i.e., the summaries are action lists)

- A prioritized list of actions based on explicitly stated ranking and importance criteria
- A management decision basis for selecting the prioritized actions for disposition in the production phase where scientific analysis and model reports are being revised per the action lists (Phase 2).

The checklists and action items for the scientific analyses, model reports, engineering calculations, and parameter traces are captured in an electronic file.

Other Independent Reviews–Peer reviews have been conducted for waste package materials performance, igneous consequences, and TSPA site recommendation. These formal peer reviews commented on approaches for testing and model development, and in many cases suggested viable alternative models and data sources. These reports were used by DOE to ensure that a sound technical basis would be developed and available to support the license application, and would also include appropriate consideration of uncertainty.

Summary for general questions related to implementation of guidance:

Based on actions taken in response to audits, surveillances, self-assessments, and management reviews conducted to evaluate the effectiveness of the products prepared to support the TSPA-LA, the DOE believes the range of concerns expressed in these agreements and AINs have been addressed.

Response for Specific Issue Raised in GEN 1.01:

Comment 78–This item questions whether uncertainties contributing to model output are represented in the abstraction to the TSPA-LA. This issue is covered in Section 3.2.1 of the guidelines in the description of duties for the subject matter expert and the abstraction team lead:

In constructing the model abstraction, the subject matter expert and process modelers must consider the level of resolution of the process model and the level of resolution in the TSPA-LA model components. The subject matter expert and process modeler will work in consultation with the abstraction team lead and TSPA analyst during the model abstraction development to achieve those goals. This includes soliciting and receiving written recommendations from the abstraction team lead and PTL regarding selection of any conservative components, parameter uncertainties, evaluation of linear and non-linear models when conservatism is used, and handling of any important parameter uncertainties and variabilities. Consequently, the model abstractions used in the TSPA-LA capture the important uncertainty and variability of the underlying process model. A description of how this uncertainty and variability was captured is found in the corresponding model report. The subject matter expert and process modeler are responsible for developing, validating, and documenting the model abstraction in the respective model report per the requirements of AP-SIII.10Q.

Comment 96–This comment raises issues regarding an analysis of water penetration into superheated rock using the Phillips analytical solution. This is also the subject of KTI Agreement TEF 2.08, the response to which was submitted to the NRC in Appendix A of *Technical Basis Document No. 3: Water Seeping into Drifts*. In that report, a comparison between results of the Phillips model and the thermal-hydrologic seepage model is thoroughly documented. The

Phillips model, with an improved semi-analytical solution, was used as an alternative conceptual model for thermal seepage, and, as such, results from this model are also documented in *Drift-Scale Coupled Processes (DST and TH Seepage) Models* (BSC 2004c). The latter report describes the current thermal-hydrologic seepage model, which is abstracted for the TSPA-LA in *Engineered Barrier System: Physical and Chemical Environment* (BSC 2004d).

The information in this enclosure is responsive to AIN requests TSPAI 3.38 AIN-1, TSPAI 3.39 AIN-1, TSPAI 3.41 AIN-1, TSPAI 4.01 AIN-1, and GEN 1.01 (Comments 78 and 96) made between DOE and NRC. This enclosure contains the information that DOE considers necessary for NRC review for closure of these agreements.

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ENCLOSURE 4

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENTS FOR TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI 4.03, 4.04, AND GEN 1.01 (COMMENT 111))

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application (LA) as the approved analyses of record at the time of LA submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the LA.

ENCLOSURE 4

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENTS FOR TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI 4.03, 4.04, AND GEN 1.01 (COMMENT 111))

BACKGROUND

Agreements were reached for TSPAI 4.03 and TSPAI 4.04 during the Technical Exchange and Management Meeting on Total System Performance and Integration held August 6 through 10, 2001, in Las Vegas, Nevada. The U.S. Nuclear Regulatory Commission (NRC) documented the agreements in a letter dated August 23, 2001 (Reamer 2001).

In response to TSPAI 4.03, the U.S. Department of Energy (DOE) provided to the NRC the report *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003). This document was transmitted to the NRC in a letter dated October 29, 2002 (Ziegler 2002).

In its transmittal letter, DOE indicated that the *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003) was the equivalent document to *Technical Document Preparation Plan for Total System Performance Assessment-Site Recommendation/License Application Methods and Assumptions* (CRWMS M&O 1999), which was the original document referenced in TSPAI 4.03. DOE also indicated that the document provides the overall approach for conducting total system performance assessment for license application model development and analyses. DOE stated that TSPAI 4.03 was partially addressed in *Total System Performance Assessment-License Application Methods and Approach* (BSC 2003), as the report provided the methodology, and the remaining portion of TSPAI (the results of the analyses) would be documented in the total system performance assessment for license application (TSPA-LA) or other appropriate documentation, as stated in the agreement.

NRC responded to DOE, citing the status of TSPAI 4.03 as partially received in a letter dated April 4, 2003 (Schlueter 2002).

GEN 1.01 (Comment 111) was discussed with DOE, and DOE provided initial responses during a Technical Exchange and Management Meeting on Range of Thermal Operating Temperatures held September 18 and 19, 2001 (Reamer and Gil 2001). The figures and tables in the text of the comment and DOE initial response to the comment are found in Volume 1 of *FY 01 Supplemental Science and Performance Analyses, Volume 1: Scientific Bases and Analyses* (BSC 2001).

The wording of the agreements and GEN 1.01 (Comment 111) are as follows:

TSPAI 4.03

> DOE will document the method that will be used to demonstrate that the overall results of the TSPA are stable. DOE will provide documentation that submodels (including submodels used to develop input parameters and transfer functions) are also numerically stable. DOE will address in the method the stability of the results

with respect to the number of realizations. DOE will describe in the method the statistical measures that will be used to support the argument of stability. The method will be documented in TSPA LA Methods and Assumptions Document in FY02. The results of the analyses will be provided in the TSPA (or other appropriate documentation) for any potential license application in FY 2003.

TSPAI 4.03 AIN-1

In addition to the information that DOE has already acknowledged that it needs to provide in response to this agreement - i.e., the results of the analyses (used to demonstrate stability), which are to be provided in the TSPA to support the potential LA (or any other appropriate documentation) - the following information is needed from DOE. 1) A description of the method that will be used to demonstrate stability in the TSPA to support the potential LA. As indicated in the Methods and Approach Document, DOE has not yet decided on its approach. 2) Documentation that submodels (including submodels used to develop input parameters and transfer functions) are numerically stable, as requested in the original agreement.

TSPAI 4.04

DOE will conduct appropriate analyses and provide documentation that demonstrates the results of the performance assessment are stable with respect to discretization (e.g., spatial and temporal) of the TSPA model. This will be documented in the TSPA for any potential license application in FY 2003.

GEN 1.01 COMMENT 111

Page 6F-3: The information presented in Figure 6.3.1.4-2 potentially indicates that the time-steps utilized for the THC simulations may be too coarse and therefore important information may be eliminated. The liquid saturation is shown to go from 0.0 to 0.10 in one time step, whereas the rewetting process would be expected to be a gradual process.

Initial DOE Response to Comment 111 (from September 18 to 19, 2001, meeting)

The interval between points at 0.0 and 0.10 liquid saturation in Figure 6.3.1.4-2 is not the time step utilized for the THC simulations. This is only the printout interval of data calculated in the model (here several hundred years) (i.e., the first point shown after rewetting is the first output non-zero saturation). The actual simulation time step is much smaller (1 to 2 years). Therefore, the actual simulated rewetting is more gradual than the data shown on these graphs. As far as which output data should be used to feed downstream models (i.e. data for which time step(s) should be used to characterize the rewetting period) this question is more an abstraction question than a THC modeling question. First output saturations after rewetting (at a given time) also depend on rock properties.

In other simulations presented in Section 6.3.1.5 for a different rock unit (Tptpll instead of Tptpmn), the first output fracture saturations are around 0.022 (e.g., Figure 6.3.1.5-2). In any case, these data were abstracted and averaged over a large time interval (e.g., from 1501 to 4000 yr in Table 6.3.1.6-2). Liquid saturations were not taken into account in the averaging process, which was reasonable because saturation values do not change much during the averaged time interval (by a factor of approximately 2 or less). One could argue that if concentrations at earlier, very small liquid saturations were included in the averaging process, then one would have to weight these concentrations in function of their corresponding liquid saturations. In this case, the resulting effect would be minimal on the averaged values. In this respect, we believe that the current abstracted data and abstraction method are reasonable.

The question concerning time-stepping in the THC abstraction used in TSPA will be addressed as part of KTI agreement TSPAI 4.04." [2]

Note 2 - Should the site be approved, DOE will, as appropriate, re-evaluate the impact of a lower temperature operating mode upon existing KTIs, which were established on the basis of the higher temperature operating mode.

RESPONSE

This response addresses KTI agreements for Total System Performance Assessment and Integration (TSPAI) 4.03, 4.03 Additional Information Needed (AIN)-1, 4.04, and General Agreement (GEN) 1.01 Comment 111. The agreements generally address the performance of the TSPA-LA model stability with respect to temporal and spatial discretization. Sufficient runs of the model have been conducted to demonstrate stability with respect to discretization. The TSPA-LA model, which will be available at license application, addresses and documents that the overall results of the TSPA and submodels (including submodels used to develop input parameters and transfer functions) are numerically stable, etc.

BASIS FOR THE RESPONSE

The model stability is addressed through several analyses documented in the TSPA-LA Section 7. These include evaluations of number realizations, time-stepping, number of particles required for unsaturated zone transport, and spatial discretization. Both TSPA-LA model runs and postprocessing of those results were conducted to evaluate the stability of the model results. Model stability will be documented in the TSPA-LA model report.

In the TSPA-LA, Latin hypercube sampling is used for the propagation of uncertainty. This sampling technique has been selected, as in past TSPAs, because of the efficient manner in which it stratifies across the range of each uncertain variable and the stability it provides for uncertainty and sensitivity analysis results in performance assessments of complex systems. In the TSPA-LA, stability relates to how much variability takes place in the outcome of interest as the model results are repeatedly calculated with different samples. Theoretical results indicate that, under certain conditions, Latin hypercube sampling does indeed exhibit better statistical convergence properties than random sampling. However, these results are difficult to apply in practice. As a result, a practical method of assessing the stability of the results obtained with Latin hypercube sampling is used.

The main issue regarding stability of the TSPA-LA model results is whether enough Monte Carlo realizations have been performed to adequately quantify the uncertainty in the dose estimates. Specifically, Section 2.2.1.4.1.3 of NUREG-1804, *Yucca Mountain Review Plan, Final Report* (NRC 2003), mentions this as an acceptance criterion, stating:

> A sufficient number of realizations has been obtained, for each scenario class, using the total system performance assessment code, to ensure that the results of the calculations are statistically stable.

Another concept associated with the probabilistic model calculations is the reliability, or confidence, in the mean annual dose estimates. The stability and reliability of the TSPA-LA results are important to validation and confidence building. For the purposes of this discussion of statistical convergence of TSPA-LA model results, the following definitions are used:

- Stability—the sensitivity of expected dose to sample size, and therefore a reflection of the accuracy of the Monte Carlo simulation methodology.

- Reliability—the uncertainty in estimates of the expected annual dose, and therefore a reflection of the precision of the Monte Carlo simulation methodology.

The TSPA-LA model was run multiple times, with a different number of realizations each time, to examine the convergence behavior of the expected dose and address the stability question. The confidence intervals for the estimated value of the expected dose were computed to address the reliability question. These results will be documented in the TSPA-LA model report.

Several techniques were used to address the stability and reliability of TSPA-LA results. These techniques are drawn from previous TSPAs, other radioactive waste performance assessment programs (e.g., Waste Isolation Pilot Plant, Atomic Energy of Canada, Ltd.), and the probabilistic risk analysis literature. The multiple techniques utilized to evaluate the stability and reliability of the TSPA-LA model results included:

- Graphical comparison of the computed model outcome (e.g., expected dose) versus sample size (for time-dependent problems, the model outcomes for different sample sizes can be overlain on the same graph to facilitate a comparative analysis)

- Testing for difference in means is used to assess the statistical significance of the difference in mean doses obtained from samples of two different sizes

- Testing for difference in distributions is a statistical ranking test performed to assess whether two different distributions are statistically alike (i.e., there is no significant shift in the magnitude of the values of the distributions)

- Application of a statistical quitting rule is applied to estimate the required number of model realizations needed to obtain stable results

- Replicated sampling is a procedure used to provide an effective approach to estimating the potential sampling error in quantities derived from Latin hypercube sampling
- Bootstrap simulations are used as a numerical procedure for simulating the sample distribution and estimating its mean, standard deviation, and confidence intervals
- Nonparametric bounds are examined; if the underlying population distribution is not normal and only a small sample of the distribution is available, then the normal distribution may not be a good approximation of the sample distribution of the mean.

These techniques are used to evaluate the stability of the two nominal scenario class cases (i.e., the early failure case and the localized corrosion failure case) and the disruptive events scenario class cases (the igneous intrusive and eruptive cases, and the seismic case with and without localized corrosion). Based on these statistical evaluations, the optimal number of realizations for the TSPA-LA model is determined for each of the scenario class cases (both nominal and the two disruptive scenario classes). These results will be documented in the TSPA-LA model report.

Another issue related to the stability of the TSPA-LA model results is temporal discretization of the model. The TSPA-LA model calculates the movement of water and radionuclides through Yucca Mountain and within the saturated zone to the accessible environment over a 20,000-year time frame. In order to predict the future behavior of water and radionuclide movement, the model uses incremental time steps while solving partial differential equations for various submodels (e.g., Finite Element Heat and Mass (FEHM) for unsaturated zone transport) and model abstractions (e.g., in-package chemistry). These include abstractions to evaluate thermal-hydrologic and thermal-hydrologic-chemical environments, as well as submodels to evaluate mobilization and transport of radionuclides subject to these environments. The size of the time steps, or temporal discretization, may affect the results of model output or intermediate quantities, such as predicted mass flux. Several different TSPA-LA model runs are performed to evaluate the potential for variability in model output due to time-step size, focusing on the most significant scenario class contributing to dose.

To test the stability of TSPA-LA model results relative to changes in the time-stepping scheme, the influence of time-step changes is examined for the igneous and seismic scenarios. For each scenario, the base case is compared to two additional simulation runs.

Comparison of the TSPA-LA model runs with different time-step sizes is done with several techniques identified for testing the stability of the model. The evaluation techniques include graphical comparisons of the results, as well as statistical methods using the student-t test to compare the means and the Wilcoxon Rank Sum test to compare the distributions.

Results indicate that the TSPA-LA model provides stable results with respect to the time-stepping scheme used in the igneous intrusive and eruptive cases, as well as the seismic cases. These results of the temporal stability evaluation of the number of realizations used for determining postclosure performance for each of the scenario classes will be presented in the TSPA-LA model report.

The TSPA-LA model quantifies both aleatory and epistemic uncertainty associated with the natural and engineered systems. Part of the aleatory uncertainty addressed by the model deals with spatial variability. Different scales exist within the TSPA-LA model relative to how the spatial variability data are used. As information is used at one scale, it is combined, or averaged, in order to be used at yet a different scale. The effect of this scaling, or averaging, on model performance was evaluated.

One of the key areas within the TSPA-LA model where spatial variability is accounted for is in the multi-scale thermal-hydrologic model (BSC 2004, Section 6.3.2). In particular, this model addresses spatial variability associated with the effects of temperature within the repository horizon on relative humidity, saturation, and other physical properties. The multi-scale thermal-hydrologic model discretizes the repository region into 2,874 equal-area subdomains corresponding to 20-m repository drift segments. The results of the multi-scale thermal-hydrologic model are used in other calculations, such as quantifying seepage flux at each of the model node locations. In order to evaluate fate and transport phenomena in the Engineered Barrier System (EBS), however, the results of the multi-scale thermal-hydrologic model, as well as the seepage flux calculations, are averaged into five smaller subregions based on a grouping of the seepage flux data into five quantiles. These five subregions, or bins, are assumed to be representative of the range of conditions throughout the repository. The spatial discretization evaluation determined how representative these subregions are in comparison with the overall spatial variability simulated within the multi-scale thermal-hydrologic model (BSC 2004).

For each of the five subregions, the TSPA-LA model approximates a "most representative" set of the multi-scale thermal-hydrologic model data. The appropriateness of the most representative data set (estimated from the five subregions, as opposed to some other discretization of the spatial variability) is the main item of concern in the EBS spatial variability study. The basis for the EBS spatial variability study is to validate the TSPA-LA model in respect to multi-scale thermal-hydrologic model variability and determine the affects, if any, and quantify the impacts, if any, of limiting the EBS spatial variability within the TSPA-LA EBS submodels by using the most representative multi-scale thermal-hydrologic model curve (BSC 2004).

Results indicate that the five repository subregions are a reasonable representation of the repository. These results will be presented in the TSPA-LA model report.

The information in this enclosure is responsive to agreements TSPAI 4.03 and 4.04 and GEN 1.01 (Comment 111) made between DOE and NRC. This enclosure contains the information that DOE considers necessary for NRC review for closure of these agreements.

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ENCLOSURE 5

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (RESPONSE TO TSPAI 4.06)

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application as the approved analyses of record at the time of License Application submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the License Application.

ENCLOSURE 5

RESPONSE TO ADDRESS KEY TECHNICAL ISSUE (KTI) AGREEMENT TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI 4.06)

BACKGROUND

Agreement was reached for TSPAI 4.06 during the Technical Exchange and Management Meeting on Total System Performance and Integration held August 6 through 10, 2001 in Las Vegas, Nevada. The U.S. Nuclear Regulatory Commission (NRC) documented the agreement in a letter dated August 23, 2001 (Reamer 2001).

The wording of the agreement is as follows:

TSPAI 4.06

> DOE will document the implementation of the process for model confidence building and demonstrate compliance with model confidence criteria in accordance with the applicable procedures. This will be documented in the respective AMR revisions and made available to NRC in FY 2003.

RESPONSE

The U.S. Department of Energy (DOE) utilized multiple processes for model validation and confidence building during and after model development. Processes such as natural analogs, auxiliary analysis, and independent technical review have documented the implementation of the process for model confidence building and demonstrated compliance with model confidence criteria in accordance with the applicable procedures. This is discussed in the TSPA-LA, which will be available at license application.

BASIS FOR THE RESPONSE

The process for TSPA-LA model and submodels confidence building includes multiple methods in the model process steps. The strategy is to use validation methods to demonstrate model validation in relationship to the model's intended use and required level of confidence.

Validation Activities during Model Development

Validation activities during model development include:

- Selection of input parameters and (or) input data, and a discussion of how the selection process builds confidence in the model, which includes checking input information and models against analysis model report results, ensuring that individual submodel results do not exceed the validity range of successive submodels, and confirming that the coupling from one submodel to the next is correct

- Description of calibration activities, initial boundary condition runs, and (or) run convergences. Also included is a discussion of how the activity or activities build confidence in the model, as well as a discussion of impacts of any run nonconvergences

- Discussion of the impacts of uncertainties to model results.

Input Verification–The input verification activities include verification of the integrated model software (GoldSim), verification of dynamically linked libraries (DLLs) from the sources and from those that are generated within the TSPA-LA model, and verification of model inputs from the TSPA database. GoldSim V8.02 is the primary software used to build and run the TSPA-LA model (DOE 2004). The software was qualified in accordance with LP-SI.12Q-BSC, *Qualification of Software*. GoldSim was used to conduct the analyses for the TSPA-LA within the limitations and range of the validation guidance presented in *User's Guide, GoldSim Probabilistic Simulation Environment* (GoldSim Technology Group 2003, Appendix G).

The general approach to verifying a DLL as a single module within an integrated model is to first run a validation test example reported in an analysis model report or to run a validation test report with known results on the stand-alone implementation of a DLL in order to verify that the correct answer reported in the analysis model report can be reproduced. The next step is to run a single realization of a version of the TSPA-LA model by providing the same set of inputs to the DLL as those run for the stand-alone model. The results from the TSPA-LA model can be obtained either from an output file created by the DLL or from GoldSim elements that capture those outputs. For purposes of verification, the results calculated from the single realization of the TSPA-LA model should be equal to those calculated by the stand-alone model.

Before using parameter values in the TSPA-LA model for the performance assessment analysis, each parameter undergoes a first and second check of the parameter identification form to ensure that all information has been entered correctly. The parameter verification is documented on the parameter verification form. Only users with access to the TSPA-LA model's controlled-access input database can perform data verification. The verification process includes recording the checker's name, the date, and the time, and thus identifies the last user to change any one of the parameter categories using a parameter identification form, a parameter documentation form, a parameter value entry form, or a parameter verification form. In this way, the integrity of the data used in the TSPA-LA model is ensured. Strict control of database access as well as the documentation trail ensures the security, integrity, and traceability of information entered into or downloaded from the TSPA-LA model input database.

Calibration Activities–Include three major types of stability tests: statistical stability, temporal stability, and spatial stability or discretization. Statistical stability involves demonstrating that a sufficient number of stochastic realizations have been run to achieve numerical stability. Approaches used to evaluate the stability of model results include (1) graphical comparisons of model output at various sample sizes; (2) performing statistical tests to evaluate if the expected dose obtained with two different sample sizes are equal; (3) performing statistical tests to evaluate if the distributions of dose obtained with two different sample sizes are equal; and (4) performing a statistical test that prescribes the number of realizations needed to meet specific confidence criteria for model results (referred to as a quitting rule).

Temporal stability uses the appropriate time step size necessary to achieve an accurate solution and is accomplished empirically by successive halving of the time step. The TSPA-LA model uses incremental time steps while solving partial differential equations for various submodels and model abstractions. The size of the time steps, which is also known as temporal discretization, may affect either the results of model output or intermediate quantities, such as predicted mass flux. If different time-step sizes are used, the time-averaging calculations could potentially result in different output.

Numerical dispersion may also be affected by time-step size. Spatial stability quantifies both aleatory and epistemic uncertainty associated with the natural and engineered systems. Part of the aleatory uncertainty addressed by the model deals with spatial variability. Different scales exist within the TSPA-LA model relative to how the spatial variability data are used. As information is used at one scale, it is combined, or averaged, in order to be used at yet a different scale. The effect of this scaling, or averaging, on model performance is a potential issue. Section 7.3 of the TSPA-LA provides additional details on calibration activities.

Uncertainty–Impacts are assessed using a number of activities, including a discussion of parameter uncertainty in the model, a discussion of the effect of risk dilution on results, and the uncertainty sensitivity analyses utilizing scatter plots, linear regression models, entropy analysis, and classification tree analysis. Model uncertainty includes both mathematical and conceptual uncertainty. Mathematical model uncertainty is a result of simplifying assumptions and approximations made in mathematical representations of phenomena describing engineered and natural barrier system performance. The adequacy of mathematical models in simulating real processes is determined by comparing the predictions of such models to field tests, laboratory experiments, and data from natural analogs. Conceptual model uncertainty refers to a state of incomplete understanding, where multiple alternative process models may be considered equally likely or defensible for any given component of the disposal system. Such uncertainty is addressed by explicitly evaluating the effects of an ensemble of plausible alternative models. Section 7.5 of the TSPA-LA provides additional details on uncertainty.

Validation Activities after Model Development

Validation activities after model development include:

- Natural Analog–Corroboration of model results with data acquired from the laboratory, field experiments, analog studies, or other relevant observations, which were not previously used to develop or calibrate the model

- Independent Technical Review–Planned in the applicable technical work plan and examined by reviewers independent of the development, checking, and interdisciplinary review of the model documentation

- Auxiliary Analysis–Corroboration of abstraction or system model results to the results of the validated mathematical model(s) from which the abstraction or system model was derived, including corroboration with results of auxiliary analyses used to provide additional confidence in system model results.

Natural Analogs–Corroboration of the results of the TSPA-LA model can be gained, in part, through comparison with natural analogs. Natural analog results served as input to the analysis model reports and were used in the validation process for the model components and submodels that they describe. Some natural analogs to materials intended for use in the Yucca Mountain repository were considered for waste package degradation and engineered barrier components. Natural analogs were also considered for geological processes such as drift stability, seepage, unsaturated and saturated zone flow and transport, coupled processes, biosphere, seismicity, and volcanism.

Independent Technical Review–In accordance with *Technical Work Plan for: TSPA-LA Model Development, Initial Use, and Documentation* (BSC 2004a), a team consisting of several off-project consultants performed an independent technical review in accordance with procedure AP-SIII.10Q Section 5.3.2.c (5). The reviewers were senior scientists and engineers with training and experience in the implementation of performance assessment methodology for complex systems related to nuclear waste repository licensing and development and the use of complex models related to waste isolation and containment. This included, but was not limited to, geology, hydrology, metallurgy, volcanism, physics, and chemistry, which are relevant to systems and processes associated with a large scale nuclear waste repository.

Prior to initiating review activities, reviewers completed all training matrix requirements specific to their job assignment and discipline. They must also complete AP-SIII.10Q, *Models* training.

The review criteria described in *Technical Work Plan for: TSPA-LA Model Development, Initial Use, and Documentation* (BSC 2004a) are presented below in three sections: general review criteria, specific review criteria for submodels, and specific review criteria for total system models. The review did not include a critique of supporting documents, though they may be used for background information (see the specific review criteria for the total system model). The models in these documents have been validated independently. This independent review has been conducted in accordance with the provisions of AP-SIII.10Q.

This review assumed four conditions prior to finalization of findings related to the particular condition:

1. The features, events, and processes (FEPs) identification and screening process is complete.

2. TSPA-LA submodels are validated, and supporting analyses and direct input to TSPA-LA are qualified. Submodels provided to TSPA-LA may be To Be Verified (TBV) during the initial phase of the validation review, but must be finalized prior to finalization of the validation review.

3. TSPA-LA submodels use parameter values, assumed ranges, probability distributions, and (or) bounding assumptions that reasonably account for uncertainties and variabilities.

4. The effort that the review team expends on validating particular individual submodels within the TSPA-LA is commensurate with the importance of the submodel to the

overall system performance. This is determined to the greatest extent possible by analysis of the TSPA-LA model preliminary results.

The independent technical review determines and documents whether or not the following general and specific criteria are achieved. The review criteria listed in *Technical Work Plan for: TSPA-LA Model Development, Initial Use, and Documentation* (BSC 2004a) are provided as a basis for the independent technical review team in their deliberations of whether the TSPA-LA model has been correctly validated in accordance with the provisions of AP-SIII.10Q, *Models*.

The general criteria for this independent technical review are as follows. The evaluation of the review team must be justified for each criterion.

1. The conceptual model of the total system is reasonable and appropriate for its intended use.

2. The FEPs identified as included in the process models and their interactions are accounted for.

3. For given inputs, the outputs of the model are reasonable (subsystem and system level results review). That is, the results should be within 1 order of magnitude of the expected results for selected, stylized analyses. This provides confidence that the subsystem and system level models capture the appropriate processes.

4. Limitations of the total system model and its submodels are adequately addressed.

5. The confidence building analyses clearly demonstrate the functionality and applicability of the model to the system being modeled.

The specific review criteria for submodels included in the TSPA-LA were as follows. The judgments of the reviewers are based on their expertise and justified in the review documentation.

1. Each submodel implemented in the TSPA-LA uses assumptions and technical bases that are appropriate and reasonably consistent with other related submodels, and if not, the differences are described and justified.

2. Models implemented in the total system performance assessment as abstractions provide results consistent with output from detailed process-level models and (or) empirical observations as documented in the supporting document (laboratory and field testing and (or) natural analogs). Some natural analog comparisons may be made in the TSPA-LA documentation to further build confidence in the underlying models.

3. Outputs from submodels are correctly linked to related submodels that receive this output as input (verification).

4. Time steps and spatial discretization selection ensure that important features of outputs of submodels are captured and represented when provided as inputs to other submodels.

5. Submodel outputs in TSPA-LA are within the range of validity for models that use the output as input, and if not, are properly constrained.

The specific review criteria for the total system model are as follows. The judgments of the reviewers were based on their expertise and justified in the review documentation.

1. The total system performance assessment sampling method ensures that sampled parameters have been sampled across their ranges of uncertainty.

2. Boundary and initial conditions used in the total system performance assessment submodels and abstractions are propagated consistently throughout the abstraction approaches.

3. TSPA-LA-specific models use parameter values, assumed ranges, probability distributions, bounding assumptions, or a combination of these, that are technically defensible and reasonably account for uncertainties and variabilities. (TSPA-LA submodels have already had this review.)

4. Alternative modeling approaches of features, events, and processes as identified in supporting documents are considered in TSPA-LA and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in each submodel and abstraction.

5. Assumptions made within the total system performance assessment model are reasonably consistent among the different components of the TSPA-LA model or the differences are described and justified. The level of consistency necessary is based on the judgment of the experts and justified in their review comments.

6. Parameters used in the implementation of the TSPA-LA model are technically justified as appropriate.

7. The number of realizations utilized for each scenario class in the TSPA-LA model is sufficient to ensure that the results of the calculations are statistically stable.

8. Total system performance forecasts and the relative performance and roles of individual components or subsystems are consistent and reasonable.

9. The numerical results are well understood and can be related to how the system evolves and which processes, factors, or parameters are most important. That is, the results have been thoroughly analyzed (e.g., regression analysis, sensitivity analyses) and documented to describe which parts of the system are causing the particular calculated response. Anomalous, nonintuitive results must be carefully explained.

10. The total system performance assessment software (GoldSim) is properly verified, such that there is confidence that the software is modeling the physical processes in the repository system in the intended manner.

The review team was provided access to the TSPA-LA document after a preliminary check, the appropriate GoldSim model files, GoldSim Player, the TSPA-LA database, results of requested TSPA-LA validation analyses, and all supporting reports. Documents used directly in TSPA-LA model and documentation include:

- *Abstraction of Drift Seepage* (BSC 2004b)
- *Analysis of Infiltration Uncertainty* (BSC 2003a)
- *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004c)
- *Calibrated Properties Model* (BSC 2003b)
- *Clad Degradation—Summary and Abstraction for LA* (BSC 2003c)
- *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004d)
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003d)
- *Dissolved Concentration Limits of Radioactive Elements* (BSC 2003e)
- *Drift-Scale Radionuclide Transport* (BSC 2004e)
- *DSNF and Other Waste Form Degradation Abstraction* (BSC 2003f)
- *EBS Radionuclide Transport Abstraction* (BSC 2001)
- *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003g)
- *Future Climate Analysis* (BSC 2003h)
- *General and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003i)
- *Defense HLW Glass Degradation Model* (BSC 2004f)
- *Initial Radionuclide Inventories* (BSC 2004g)
- *In-Package Chemistry Abstraction* (BSC 2003j)
- *Saturated Zone Flow and Transport Model Abstraction* (BSC 2003k)
- *Advection Versus Diffusion in the Invert* (BSC 2003l)
- *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003m)
- *Multiscale Thermohydrologic Model* (BSC 2004h)

- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003n)
- *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2004i)
- *Particle Tracking Model and Abstraction of Transport Processes* (BSC 2004j)
- *Engineered Barrier System: Physical and Chemical Environment* (BSC 2004k)
- *Radionuclide Transport Models under Ambient Conditions* (BSC 2003o)
- *Seepage Model for PA Including Drift Collapse* (BSC 2004l)
- *Seismic Consequence Abstraction* (BSC 2004m)
- *UZ Flow Models and Submodels* (BSC 2004n)
- *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003p)
- *Igneous Intrusion Impacts on Waste Package and Waste Forms* (BSC 2004o).

Other information needed by the review team to conduct their activities is provided as requested.

Review of the model was conducted using electronic comment resolution files to facilitate the configuration management of comments and their resolutions.

The team provided detailed documentation of its validation review; the documentation addresses each of the review criteria. The review will be summarized in section 7 of the TSPA-LA and included as an appendix to the document. The summary and supporting appendix supports the claim that the validation review was a thorough evaluation of the TSPA-LA and its supporting documentation.

Auxiliary Analyses–Confidence building activities are often based on the use of stylized inputs or test cases that help demonstrate that the TSPA-LA model and its components and submodels are functioning correctly. It can be postulated a priori that the TSPA-LA model ought to behave in a certain way or produce certain results when it is exercised in a specific fashion. If the simulated outputs from these stylized cases run counter to scientific judgment and intuition, then confidence in the model would be weakened and an explanation of these counter-intuitive results would have to be sought by means of deeper analyses of the underlying processes. Conversely, if the results of the stylized cases produce results that seem logical, confidence in the model is enhanced.

The auxiliary or stylized analyses include simple test cases such as using simplified or constant inputs and (or) back-of-the-envelope calculations; complete analysis of selected realizations (e.g., upper-bound realizations) from the full suite of probabilistic realizations; barrier neutralization analyses; analyses to examine selected submodel results; integration analyses to examine important interfaces between model components; and analyses of DOE spent fuel categories to examine the use of surrogates that represent DOE spent fuel in the TSPA-LA model. These types of simulations and analyses help test the different model components and their interactions within the TSPA-LA model and provide an enhanced understanding of the performance of the system and its parts, including an understanding of causal relationships that, in turn, generate confidence in the TSPA-LA model. Much of the documentation produced in this activity is included as part of the previously described independent technical review to help facilitate the review.

Summary–Successful completion of all three activities of postdevelopment model validation demonstrates that the TSPA-LA Model is validated according to AP-SIII.10Q, Section 5.3.2c, and that its results can be used with confidence in assessing the postclosure performance of the Yucca Mountain repository.

The information in this enclosure is responsive to agreement TSPAI 4.06 made between DOE and NRC. This enclosure contains the information that DOE considers necessary for NRC review for closure of this agreement.

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