4.2 Repository Safety After Permanent Closure

4.2.1 Performance Assessment

Risk-Informed Review Process for Performance Assessment—The performance assessment quantifies repository performance, as a means of demonstrating compliance with the postclosure performance objectives at 10 CFR 63.113. The U.S. Department of Energy performance assessment is a systematic analysis that answers the triplet risk questions: what can happen; how likely is it to happen; and what are the consequences. The Yucca Mountain performance assessment is a sophisticated analysis that involves various complex considerations and evaluations. Examples include evolution of the natural environment, degradation of engineered barriers over a 10,000-year period, and disruptive events, such as seismicity and igneous activity. The staff needs to consider the technical support for models and parameters of the performance assessment, based on detailed process models, laboratory and field experiments, and natural analogs. In their evaluation of the technical support for models and parameter distributions, the staff will consider the implications for the repository system and the effects on the calculated dose. Because the performance assessment encompasses such a broad range of issues, the staff needs to use risk information throughout the review process. Using risk information will ensure the review focuses on those items most important to performance.

Section 4.2.1 requires the staff to apply risk information throughout the review of the performance assessment. First, the staff reviews the barriers important to waste isolation in Section 4.2.1.1. The U.S. Department of Energy must identify the important barriers (engineered and natural) of the performance assessment, describe each barrier's capability, and provide the technical basis for that capability. This risk information describes the U.S. Department of Energy understanding of each barrier's capability to prevent or substantially delay the movement of water or radioactive materials. Staff review of the U.S. Department of Energy performance assessment—first the barrier analysis and later the rest of the performance assessment—considers risk insights from previous performance assessments conducted for the Yucca Mountain site, detailed process modeling efforts, laboratory and field experiments, and natural analog studies. The result of the initial multiple barrier review is a staff understanding of each barrier's importance to waste isolation, which will influence the emphasis placed on the reviews conducted in Sections 4.2.1.2, "Scenario Analysis and Event Probability" and 4.2.1.3, "Model Abstraction." The emphasis placed on particular parts of the staff review will change based on changes to the risk insights or in response to preliminary review results.

Scenario analysis and model abstraction are the key attributes of the performance assessment. The risk information, drawn from the review of the multiple barriers section, will direct the staff review to those topics within scenario analysis and model abstraction that are important to waste isolation. Section 4.2.1.2 provides the review methods and acceptance criteria for scenarios for both nominal and disruptive events. An acceptable scenario selection method includes identification and classification, screening, and construction of scenarios from the features, events, and processes considered at the Yucca Mountain site. Then, it is necessary to review abstracted models used in the performance assessment for the retained scenarios. The performance assessment review focuses on the 14 model abstractions in

Section 4.2.1.3 and the implementation of the model abstractions in the total system performance assessment model. These model abstractions stemmed from those aspects of the engineered, geosphere, and biosphere subsystems shown to be most important to performance, based on prior performance assessments and knowledge of site characteristics and repository design. The staff developed each of the fourteen model abstraction sections in substantial detail, to allow for a detailed review. However, it is unlikely that each of the abstractions will have the same risk significance. The staff will review the abstractions according to the risk significance determined in the multiple barrier review, using Section 4.2.1.1. Nevertheless, until the U.S. Department of Energy completes its safety case and the license application, the review plan sections dealing with model abstractions must remain flexible and in enough detail, so that the U.S. Department of Energy will understand how the U.S. Nuclear Regulatory Commission will conduct the reviews .

The review of the model abstraction process begins with the review of the repository design and the data characterizing the geology and the performance of the design and proceeds through the development of models used in the performance assessment. The model abstraction review process ends with a review of how the abstracted models are implemented in the total system performance assessment model (e.g., parameter ranges and distributions, integration with model abstractions for other parts of the repository system, representation of spatial and temporal scales, and whether the performance assessment model appropriately implements the abstracted model). Reviews conducted on the early stages of the model abstraction process will be influenced by the final application of the information. For example, the review of parameter distributions will consider the relevant data, the corresponding uncertainty, and effects on the performance of the repository (i.e., the dose to the reasonably maximally exposed individual). The potential for risk dilution—the lowering of the risk, or dose, from an unsupported parameter range and distribution—will also be part of this review of model abstraction.

An unwanted risk dilution can easily result, if care is not exercised in selecting parameter ranges. For example, the parameter range for the retardation factor of a particular radionuclide could be expanded beyond that found in the supporting data in an effort to represent uncertainty. This expanded range could increase the spread in calculated arrival time for the radionuclide and, consequently, result in a smaller expected annual dose. The staff will review parameter ranges and distributions to evaluate whether they are technically defensible, whether they appropriately represent uncertainty, and the potential for risk dilution.

In many regulatory applications, a conservative approach can be used to decrease the need to collect additional information or to justify a simplified modeling approach. Conservative estimates for the dose to the reasonably maximally exposed individual may be used to demonstrate that the proposed repository meets U.S. Nuclear Regulatory Commission regulations and provides adequate protection of public health and safety. Approaches designed to overestimate a specific aspect of repository performance (e.g., higher temperatures within the drifts) may be conservative with respect to temperature but could lead to non-conservative results with respect to dose. The total system performance assessment is a complex analysis with many parameters, and the U.S. Department of Energy may use conservative assumptions to simplify its approaches and data collection needs. However, a technical basis that supports the selection of models and parameter ranges or distributions must be provided. The staff evaluation of the adequacy of technical bases supporting models

and parameter ranges or distributions will consider whether the approach results in calculated doses that would overestimate, rather than underestimate, the dose to the reasonably maximally exposed individual. In particular, the claim of conservatism as a basis for simplifying models and parameters should be carefully evaluated to ensure that any simplifications are justified and do not unintentionally result in nonconservative results.

The intentional use of conservatism to manage uncertainty also has implications for the staff's efforts to risk-inform its review. The staff will evaluate assertions that a given model or parameter distribution is conservative from the perspective of overall system performance (i.e., the dose to the reasonably maximally exposed individual). The staff will use any available information to risk-inform its review. For example, if the U.S. Department of Energy were to use an approach that overestimates a specific aspect of repository performance, then the staff would consider the effects of this approach on other parts of the total system performance assessment model, overall repository performance, and the representation or sensitivity of important phenomena.

4.2.1.1 System Description and Demonstration of Multiple Barriers

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.1.1 Areas of Review

This section addresses review of the system description and demonstration of multiple barriers. Reviewers will evaluate the information required by 10 CFR 63.21(c)(1), (9), (10), (14), and (15).

The staff will evaluate the following parts of the system description and demonstration of multiple barriers, using the review methods and acceptance criteria in Sections 4.2.1.1.2 and 4.2.1.1.3.

- Identification of barriers relied on for postclosure performance; (including at least one barrier from the engineered system and one from the natural system);
- Description of the capability of identified barriers to prevent or substantially delay the movement of water or radioactive materials, including the uncertainty associated with this capability and the consistency with approaches used in the total system performance assessment; and
- Discussion of the technical bases for assertions of barrier capability commensurate with the importance of a particular barrier in the performance assessment and with the associated uncertainties.

4.2.1.1.2 Review Methods

Review Method 1 Identification of Barriers

Verify that the U.S. Department of Energy has described the repository system in terms of the engineered components and attributes of the geologic setting, which are barriers contributing to the postclosure performance of the repository. Confirm that the U.S. Department of Energy has clearly linked identified barriers to a capability to prevent or substantially delay the movement of water or radioactive materials. Verify that, among the materials, structures, and features and processes identified as barriers, at least one is engineered and one is part of the geologic setting.

Review Method 2 Description of Barrier Capability

Verify that the U.S. Department of Energy description of barrier capability is explained in terms of a capability to prevent or substantially delay the movement of water or radioactive materials, and includes a characterization of the related uncertainty.

Confirm that information is provided on the time period over which each barrier performs its intended function, including any changes during the compliance period.
Confirm that the U.S. Department of Energy adequately describes the capability of each barrier, including uncertainties, consistent with the quantitative analyses in the U.S. Department of Energy total system performance assessment (e.g., sensitivity and uncertainty analyses, and intermediate results for individual barriers).

To the extent possible, use information gained from alternative total system performance assessment code audit calculations and/or other appropriate quantitative analyses to confirm each barrier's capabilities.

Review Method 3 Technical Basis for Barrier Capability

Use information gained from the review conducted, using Review Method 2, to focus review of the adequacy of the technical bases. Verify Department of Energy has provided technical bases to support the descriptions of barrier capability commensurate with the significance of each barrier's capability and the associated uncertainties. Confirm the technical bases are based on and consistent with the technical bases for the performance assessment. Based on the reviews conducted using Sections 4.2.1.2 ("Scenario Analysis and Event Probability") and 4.2.1.3 ("Model Abstraction"), confirm the quality and completeness of the technical bases for the barrier capabilities.

4.2.1.1.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements at 10 CFR 63.113(a) and 63.115(a)–(c).

Acceptance Criterion 1 Identification of Barriers Is Adequate.

Barriers relied on to achieve compliance with 10 CFR 63.113(b), as demonstrated in the total system performance assessment, are adequately identified, and are clearly linked to their capability. The barriers identified include at least one from the engineered system and one from the natural system.

Acceptance Criterion 2 Description of Barrier Capability to Isolate Waste Is Acceptable

The capability of the identified barriers to prevent or substantially delay the movement of water or radioactive materials is adequately identified and described:

- The information on the time period over which each barrier performs its intended function, including any changes during the compliance period, is provided;
- The uncertainty associated with barrier capabilities is adequately described; and
- The described capabilities are consistent with the results from the total system performance assessment.

Acceptance Criterion 3 Technical Basis for Barrier Capability Is Adequately Presented.

The technical bases are consistent with the technical basis for the performance assessment. The technical basis for assertions of barrier capability is commensurate with the importance of each barrier's capability and the associated uncertainties.

4.2.1.1.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.1.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed materials, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.113(a). An engineered barrier system has been designed that, working in combination with natural barriers, satisfies the requirement for a system of multiple barriers, in compliance with the postclosure performance objectives.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed materials, and has found, with reasonable expectation, that they satisfy the requirements at 10 CFR 63.115(a)–(c). Those design features of the engineered barrier system and natural features of the geologic setting that are considered barriers important to waste isolation have been identified. A description has been provided of the capability of barriers identified as important to waste isolation to isolate waste, taking into account uncertainties in characterizing and modeling the barriers, and the technical basis for this

description has been provided that is based on and consistent with the technical basis for the performance assessment.

4.2.1.1.5 References

None.

4.2.1.2 Scenario Analysis and Event Probability

4.2.1.2.1 Scenario Analysis

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.2.1.1 Areas of Review

This section reviews identification of features, events, and processes affecting compliance with the overall performance objective. Reviewers will also evaluate the information required by 10 CFR 63.21(c)(1) and (9).

Review the U.S. Department of Energy methodology for inclusion or exclusion of features, events, and processes in the total system performance assessment. The U.S. Department of Energy is not required to use steps provided here that involve categorization and screening of the initial comprehensive features, events, and processes list for an acceptable license application. However, many steps can be used in accordance with the requirements in 10 CFR Part 63 to reduce the burden of the analysis and to focus the representation of the system on those features, events, and processes that most affect compliance with the overall performance objective. All included features, events, and processes must be appropriately incorporated into the total system performance assessment, and will be reviewed as part of the model abstraction review conducted, using Section 4.2.1.3 of the Yucca Mountain Review Plan.

To evaluate repository postclosure safety, ensure that the U.S. Department of Energy has conducted analyses that consider potential future conditions a repository may be subjected to, during the period of regulatory concern. These analyses should address those features, events, and processes necessary to describe the future evolution of the repository system.

The staff will review the following parts of the identification of features, events, and processes affecting compliance with the overall performance objective, using the review methods and acceptance criteria in Sections 4.2.1.2.1.2 and 4.2.1.2.1.3:

- Identification of an initial list of features, events, and processes;
- Screening of the initial list of features, events, and processes;
- Formation of scenario classes using the reduced set of features, events and processes; and
- Screening of scenario classes.

4.2.1.2.1.2 Review Methods

Review Method 1 Identification of an Initial List of Features, Events, and Processes

Verify that the U.S. Department of Energy list of features, events, and processes includes all features, events, and processes having a potential to influence repository performance. Use knowledge gained reviewing the Yucca Mountain site and regional characterization data and the description of the modes of degradation, deterioration, and alteration of the engineered barriers to assess the completeness of the features, events, and processes list. The staff should use, as appropriate, available generic lists of features, events, and processes (e.g., Nuclear Energy Agency, 1997), as a reference to determine the completeness of the U.S. Department of Energy list of features, events, and processes.

Review Method 2 Screening of the Initial List of Features, Events, and Processes

Examine the excluded features and processes. Evaluate the adequacy of the rationale for excluding each feature and process, based on the description of the site, the design specifications, and the waste characteristics. Consider information from site and regional characterization, natural analog studies, and the repository design, during this evaluation.

Examine the U.S. Department of Energy event-screening rationale, to determine whether an event is appropriately defined. Use the results of the review, conducted using Section 4.2.1.2.2 of the Yucca Mountain Review Plan, for this purpose. Assess the U.S. Department of Energy justification (i.e., whether the probability of occurrence can be technically supported) for those events that fall below the regulatory probability criterion, to evaluate whether the U.S. Department of Energy defined these events too narrowly, and they were inappropriately excluded.

Review the criteria used to screen features, events, and processes related to the geologic setting, and the degradation, deterioration, or alteration of engineered barriers from the performance assessment, based on their limited effect on the magnitude and time of the average annual dose. Evaluate the U.S. Department of Energy analyses or calculations supporting this screening and the use of bounding or representative estimates for the consequences. Independently assess, using tools such as an alternative total system performance assessment code, the potential consequences to confirm the U.S. Department of Energy screening of features, events, and processes.

Review Method 3 Formation of Scenario Classes Using the Reduced Set of Events

Evaluate the U.S. Department of Energy description of the approach and technical bases, to determine whether the resulting scenario classes are mutually exclusive and include all events that have not been screened from the performance assessment.

Review Method 4 Screening of Scenario Classes

Review the criteria used by the U.S. Department of Energy to screen scenario classes from the performance assessment on the basis that their omission would not significantly change the magnitude nor time of the average annual dose. Examine the U.S. Department of Energy

analyses or calculations supporting this screening and the use of bounding or representative estimates for the consequences. Independently assess, using tools such as an alternative total system performance assessment code, as needed, the potential consequences to confirm the U.S. Department of Energy screening of scenario classes.

Evaluate whether the U.S. Department of Energy has adequately considered coupling of processes in estimates of consequences used to screen scenario classes. For each screened scenario class, assess related scenario classes to evaluate whether a narrow definition resulted in the premature exclusion of the scenario class.

Examine those scenario classes excluded for the Yucca Mountain repository and the supporting technical bases. Consider the site description, design specifications, and waste characteristics in this examination. Also, consider information from site and regional characterization, natural analog studies, and repository design, in this evaluation.

Use the results of the review, conducted using Section 4.2.1.2.2 of the Yucca Mountain Review Plan, to examine the U.S. Department of Energy technical justification for screening scenario classes from the performance assessment, based on their probability of being below the regulatory criterion.

4.2.1.2.1.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements at 10 CFR 63.114(e) and (f).

Acceptance Criterion 1 The Identification of an Initial List of Features, Events, and Processes Is Adequate

- The Safety Analysis Report contains a complete list of features, events, and processes, related to the geologic setting or the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers), that have the potential to influence repository performance. The list is consistent with the site characterization data. Moreover, the comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events related to igneous activity (extrusive and intrusive); seismic shaking (high-frequency-low magnitude, and rare large-magnitude events); tectonic evolution (slip on existing faults and formation of new faults); climatic change (change to pluvial conditions); and criticality.

Acceptance Criterion 2 Screening of the Initial List of Features, Events, and Processes Is Appropriate

- The U.S. Department of Energy has identified all features, events, and processes related to either the geologic setting or to the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have been excluded;

- The U.S. Department of Energy has justified excluding each feature, event, and process. An acceptable justification for excluding features, events, and processes is that either the feature, event, and process is specifically excluded by regulation; probability of the feature, event, and process (generally an event) falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment; and

- The U.S. Department of Energy has provided an adequate technical basis for each feature, event, and process, excluded from the performance assessment, to support the conclusion that either the feature, event, or process is specifically excluded by regulation; the probability of the feature, event, and process falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.

Acceptance Criterion 3 Formation of Scenario Classes Using the Reduced Set of Events Is Adequate

- Scenario classes are mutually exclusive and complete, clearly documented, and technically acceptable.

Acceptance Criterion 4 Screening of Scenario Classes Is Appropriate

- Screening of scenario classes is comprehensive, clearly documented, and technically acceptable;

- The U.S. Department of Energy has adequately considered coupling of processes in estimates of consequences used to screen scenario classes. Scenario classes were not prematurely excluded by a narrow definition;

- Scenario classes that are screened from the performance assessment, on the basis that they are specifically ruled out by regulation or are contrary to stated regulatory assumptions are identified, and sufficient justifications are provided;

- Scenario classes that are screened from the performance assessment, on the basis that their probabilities fall below the regulatory criterion, are identified, and sufficient justifications are provided; and

- Scenario classes that are screened from the performance assessment, on the basis that their omission would not significantly change the magnitude and time of the average annual dose, are identified, and sufficient justifications are provided.

4.2.1.2.1.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.2.1.3 are appropriately satisfied, the staff concludes that this evaluation is

complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114(e) and (f) in that:

- The Safety Analysis Report provides an adequate initial list of features, events, and processes related to the geologic setting or the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have the potential to influence repository performance;
- The list of initial features, events, and processes has been appropriately screened;
- Scenario classes formed from the screened list of features, events, and processes are adequate; and
- Scenario classes have been appropriately screened.

4.2.1.2.1.5 Reference

Nuclear Energy Agency. "An International Database of Features, Events, and Processes [Draft]." Nuclear Energy Agency Working Group on the "Development of a Database of Features, Events, and Processes Relevant to the Assessment of Post-Closure Safety of Radioactive Waste Repositories, Safety Assessment of Radioactive Waste Repositories Series." United Kingdom: Safety Assessment Management Limited. June 24, 1997.

4.2.1.2.2 Identification of Events with Probabilities Greater Than 10^{-8} Per Year

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.2.2.1 Areas of Review

This section reviews identification of events with probabilities greater than 10^{-8} per year. Reviewers will also evaluate information required by 10 CFR 63.21(c)(1) and (9).

The staff will evaluate the following parts of the identification of events with probabilities greater than 10^{-8} per year, using the review methods and acceptance criteria in Sections 4.2.1.2.2.2 and 4.2.1.2.2.3:

- Definitions of events, such as faulting, seismicity, igneous activity, and criticality;
- The probability assigned to each event, and the technical bases used to support this assignment;

- Conceptual models evaluated or considered in determining the probabilities of events;
- Parameters used to calculate the probabilities of events; and
- Uncertainty in models and parameters used to calculate the probabilities of events.

4.2.1.2.2.2 Review Methods

Review Method 1 Event Definition

Evaluate whether the definitions for events (potentially beneficial or disruptive), applicable to the Yucca Mountain repository, are unambiguous; probabilities are estimated for the specific event; and event definitions are used consistently and appropriately in probability models.

Confirm that probabilities of intrusive and extrusive igneous events are calculated separately. Verify that definitions of faulting and earthquakes are derived from the historical record, paleoseismic studies, or geological analyses. Confirm that criticality events, for the purpose of initial screening of the features, events, and processes list, are calculated separately, only by location of the criticality event (e.g., in-package, near-field, and far-field).

Review Method 2 Probability Estimates

Evaluate whether the probability estimates for events applicable to Yucca Mountain are based on past patterns of natural events in the Yucca Mountain region, or are consistent with the design of the proposed repository system. Evaluate whether the U.S. Department of Energy interpretations of the likelihood of future occurrence of the events are compatible with current understandings of present and likely future conditions of the natural and engineered repository systems.

Verify that probability estimates for future igneous events are based on past patterns of igneous events in the Yucca Mountain region. Evaluate the adequacy and sufficiency of the U.S. Department of Energy characterization and documentation of past igneous activity. This should include uncertainties about the distribution, timing, and characteristics of past igneous activity. Confirm that, at a minimum, documentation of past igneous activity, since about 12 million years ago, encompasses the area within about 50 kilometers (30 miles) of the proposed repository site. Give particular attention to the documentation of the locations, ages, volumes, geochemistry, and geologic settings of less than 6-million-year-old basaltic igneous features, such as cinder cones, lava flows, igneous dikes, and sills. Verify that the U.S. Department of Energy used geological and geophysical information relevant to past igneous activity contained in the literature.

Verify that probability estimates for future faulting and seismic events are based on past patterns of these events in the Yucca Mountain region. Examine the adequacy and sufficiency of characterization and documentation of past faulting and seismicity in the Yucca Mountain region, since 2 million years ago. This should include characterization of uncertainties in the age, timing, magnitude (i.e., displacements), distribution, size, location, and style of faulting and seismicity. Evaluate whether interpretations of faulting and seismicity from surficial and underground mapping, interpretations of geophysical data, or analog investigations are

internally consistent and geologically feasible, so reasonable projections can be made about the probability of future faulting and earthquake-induced ground vibrations at the site.

Evaluate whether probability estimates for future criticality events are based on design characteristics and natural features of the proposed Yucca Mountain repository system. Ensure that the U.S. Department of Energy has included all fuel types to be disposed of at the proposed Yucca Mountain repository in calculating probability of future criticality events. Confirm that the estimate of probability of criticality is determined using methodology outlined in the "U.S. Department of Energy Topical Report on Disposal Criticality" (U.S. Department of Energy, 1998), as amended by responses to the U.S. Nuclear Regulatory Commission request for additional information,[2] and subject to conditions and limitations in the U.S. Nuclear Regulatory Commission safety evaluation report (U.S. Nuclear Regulatory Commission, 2000).

Review Method 3 Probability Model Support

Confirm that a technical justification is provided for models used to estimate the probability for events applicable to the Yucca Mountain repository. Determine whether justifications include comparison with results from detailed process models, or comparison with empirical observations, such as reasonably analogous natural systems or appropriate laboratory tests. Ensure that alternative modeling approaches, consistent with available data and current scientific understanding, are investigated, and results and limitations are appropriately factored into the probability models.

Examine whether the U.S. Department of Energy probability models are consistent with known less than 12-million-year-old basaltic igneous events in the Yucca Mountain magmatic system. Determine whether the U.S. Department of Energy probability models are consistent with patterns of igneous activity in other, comparable volcanic fields outside the Yucca Mountain region. Use independent models to estimate the probabilities of igneous activity, based on geologic information from the Yucca Mountain region. Verify that the U.S. Department of Energy considered alternative interpretations of probability for igneous events. Assess whether igneous-activity probability models are consistent with the range of tectonic models used to assess other geological processes, such as seismic source characterization, site geological models, and patterns of ground-water flow.

Determine whether results of the U.S. Department of Energy probabilistic and total system performance assessment models compare reasonably to results from seismotectonic process models, and/or empirical observations from appropriate analogs. Verify that the U.S. Department of Energy appropriately adopted acceptable and documented procedures, to construct and test empirical and physical models used to estimate the seismic and fault-displacement hazards. For faulting, ascertain whether the U.S. Department of Energy models, used to describe primary and secondary (or distributed) faulting, are justified technically, and are adequate to predict the effects of faulting on repository performance. For seismicity, determine whether the U.S. Department of Energy considered credible alternative modeling

[2]U.S. Department of Energy. "U.S. Department of Energy (DOE) Response to U.S. Nuclear Regulatory Commission Request for Additional Information on the DOE Topical Report on Disposal Criticality Analysis Methodology." Letter (November 19) to C.W. Reamer, U.S. Nuclear Regulatory Commission. Washington, DC: U.S. Department of Energy. 1999.

approaches for determining tectonic ground motions that relate to repository performance. Assess whether faulting models are consistent with fault-slip rates, fault displacements, or earthquake data used in the seismic hazard analysis; and evaluate whether the timing and magnitude of future seismic events are consistent with the results of the fault-hazard analysis.

Confirm that models, used to estimate the probability of future criticality events, are validated, using methodology outlined in the "U.S. Department of Energy Topical Report on Disposal Criticality" (U.S. Department of Energy, 1998), as amended by responses to the U.S. Nuclear Regulatory Commission request for additional information,[3] and subject to conditions and limitations contained in the U.S. Nuclear Regulatory Commission safety evaluation report (U.S. Nuclear Regulatory Commission, 2000).

Probability model support for infrequent events should include data from analog systems that contain significantly more events than the Yucca Mountain system. This support should also include justification that the models reproduce the timing and characteristics of past events in the Yucca Mountain system. Confirm that probability models for natural events use geologic bases that are consistent with other relevant features, events, and processes.

Review Method 4 Probability Model Parameters

Determine whether the parameters used to calculate the probability of events, applicable to the Yucca Mountain repository, are reasonable, based on data from the Yucca Mountain region or analogous natural systems, and/or design and engineering characteristics of the proposed Yucca Mountain repository system.

Assess whether the parameters used in probabilistic volcanic hazard assessments are reasonable, based on data from the Yucca Mountain region, and confirm that comparable volcanic systems outside the Yucca Mountain region were considered in developing such parameters.

Verify whether parameter values used in probabilistic seismic and fault-displacement hazard assessments are adequately supported by Yucca Mountain region faulting and earthquake data or appropriate analogs, so the effects of faulting and seismicity are appropriately factored into repository performance. Ensure that parameters are consistent with the range of faulting characteristics and seismicity observed in the Yucca Mountain region, or with parameters derived from representative analogs, and ascertain that the parameters account for variability in data precision and accuracy. For example, determine whether the U.S. Department of Energy adequately evaluated uncertainties in faulting or earthquake activity (i.e., recurrence). Confirm that the U.S. Department of Energy has established reasonable and consistent correlations between parameters, where appropriate.

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[3]U.S. Department of Energy. "U.S. Department of Energy (DOE) Response to U.S. Nuclear Regulatory Commission Request for Additional Information on the DOE Topical Report on Disposal Criticality Analysis Methodology." Letter (November 19) to C.W. Reamer, U.S. Nuclear Regulatory Commission. Washington, DC: U.S. Department of Energy. 1999.

Where sufficient data do not exist, confirm that parameter values and conceptual models are based on appropriate use of other sources, such as expert elicitation, using NUREG–1563 (Kotra, et al., 1996).

Review Method 5 Uncertainty in Event Probability

For events applicable to the Yucca Mountain repository, determine whether the U.S. Department of Energy has adequately identified and propagated uncertainties in estimating probabilities. Ensure that an adequate technical basis, that includes treatment of uncertainty, is provided for the probability value. For probability distributions or ranges, confirm that a technical basis for the analysis is provided, and that the distribution or range accounts for the uncertainty in the probability estimates.

Assess the probability values used for igneous events by considering the range of values available in the literature for the Yucca Mountain region and comparable volcanic fields outside the Yucca Mountain region. To confirm that probability models are sufficiently robust to reasonably approximate the distribution of Yucca Mountain region igneous features, evaluate probability models by testing their sensitivity to uncertainties about the past distribution of volcanic vents, recurrence rates of volcanism, and relationships between igneous activity and tectonism.

Verify that probabilities used in the evaluation of faulting and seismicity effects on repository performance include both infrequent seismic and faulting events with relatively large-magnitude ground motions and fault displacements, and the cumulative effects of repeated ground motions or fault displacements from more frequent and lower-magnitude seismic or faulting events.

4.2.1.2.2.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements at 10 CFR 63.114(d).

Acceptance Criterion 1 Events Are Adequately Defined.

- Events or event classes are defined without ambiguity and used consistently in probability models, such that probabilities for each event or event class are estimated separately; and

- Probabilities of intrusive and extrusive igneous events are calculated separately. Definitions of faulting and earthquakes are derived from the historical record, paleoseismic studies, or geological analyses. Criticality events are calculated separately by location.

Acceptance Criterion 2 Probability Estimates for Future Events Are Supported by Appropriate Technical Bases.

- Probabilities for future natural events are based on past patterns of the natural events in the Yucca Mountain region, considering the likely future conditions and interactions of

the natural and engineered repository system. These probability estimates have specifically included igneous events, faulting and seismic events, and criticality events.

Acceptance Criterion 3 Probability Model Support Is Adequate.

- Probability models are justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, or natural analogs, including Yucca Mountain site data). Specifically:

  — For infrequent events, the U.S. Department of Energy justifies, to the extent possible, proposed probability models with data from reasonably analogous systems. Analog systems should contain significantly more events than the Yucca Mountain system, to provide reasonable evaluations of probability model performance;

  — The U.S. Department of Energy justifies, to the extent possible, the ability of probability models to reproduce the timing and characteristics (e.g., location and magnitude) of successive past events in the Yucca Mountain system; and

  — The U.S. Department of Energy probability models for natural events use underlying geologic bases (e.g., tectonic models) that are consistent with other relevant features, events, and processes evaluated, using Section 4.2.1.2.1.

Acceptance Criterion 4 Probability Model Parameters Have Been Adequately Established.

- Parameters used in probability models are technically justified and documented by the U.S. Department of Energy. Specifically:

  — Parameters for probability models are constrained by data from the Yucca Mountain region and engineered repository system to the extent practical;

  — The U.S. Department of Energy appropriately establishes reasonable and consistent correlations between parameters; and

  — Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of other sources, such as expert elicitation conducted in accordance with appropriate guidance.

Acceptance Criterion 5 Uncertainty in Event Probability Is Adequately Evaluated.

- Probability values appropriately reflect uncertainties. Specifically:

  — The U.S. Department of Energy provides a technical basis for probability values used, and the values account for the uncertainty in the probability estimates; and

  — The uncertainty for reported probability values adequately reflects the influence of parameter uncertainty on the range of model results (i.e., precision) and the

model uncertainty, as it affects the timing and magnitude of past events (i.e., accuracy).

4.2.1.2.2.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.2.2.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed materials, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114(d). The license application considers those events that have at least one chance in 10,000 of occurring over 10,000 years.

4.2.1.2.2.5 References

Kotra, et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

U.S. Department of Energy. "Disposal Criticality Analysis Methodology Topical Report." YMP/TR–004Q. Revision 0. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. November 1998.

U.S. Nuclear Regulatory Commission. "Draft Safety Evaluation Report on Disposal Criticality Analysis Methodology Topical Report." Revision 0. Washington, DC: U.S. Nuclear Regulatory Commission. 2000.

4.2.1.3 Model Abstraction

There are 14 model abstraction sections the staff will use to determine compliance with 10 CFR 63.114. The abstractions consider the engineered, geosphere, and biosphere subsystems that may be important to performance. Important to performance means important to meeting the performance objectives specified in 10 CFR 63.113 The staff will decide which abstractions are important to performance, by using risk insights gained from performance assessments, knowledge of site characteristics and repository design, and review of the U.S. Department of Energy safety case. Each section provides enough review methods and acceptance criteria to allow for a detailed review. However, it is unlikely that each of the 14 abstraction topics will have the same risk significance and need the same review level. Nevertheless, until the U.S. Department of Energy completes its safety case and the license application, the sections about model abstractions need to be flexible and in enough detail that the staff clearly understands how to conduct the review of abstraction information provided by the licensee. The staff will focus its review to understand the importance to performance of the various assumptions, models, and data in the performance assessment. The staff will also focus its review to ensure that the degree of technical support for models and data abstractions

is equal to their contribution to risk. This means the staff will review each model abstraction to a detail level suitable to the degree the U.S. Department of Energy relies on it to prove its safety case. The staff will be familiar with the U.S. Department of Energy safety case, because of the multiple barrier review (refer to Section 4.2.1.1). In the multiple barrier review, the staff will evaluate the capability of the barriers. For example, if the U.S. Department of Energy relies on the unsaturated zone to provide significant delay in the transport of radionuclides to the reasonably maximally exposed individual, then the staff will perform a detailed review of the abstraction of radionuclide transport in the unsaturated zone. However, if the U.S. Department of Energy shows that this abstraction has a minor impact on the delay in the transport of radionuclides to the reasonably maximally exposed individual, then the staff will conduct a simplified review focusing on the bounding assumptions. The staff will use the review methods and acceptance criteria in these sections to decide whether the U.S. Department of Energy properly characterized the features, events, and processes and properly factored them into the performance assessment. This is necessary to decide whether the U.S. Department of Energy performance assessment is acceptable and complies with 10 CFR 63.114 and 63.115. The review methods and acceptance criteria the staff will use to evaluate compliance with the performance objectives (numerical standard) are in Section 4.2.1.4 of the Yucca Mountain Review Plan.

4.2.1.3.1 Degradation of Engineered Barriers

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which degradation of engineered barriers affects the U.S. Department of Energy safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on the engineered barriers to provide significant delay in the transport of radionuclides to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the dose to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary in a simplified review for those abstractions that have a minor impact on performance. The demonstration of compliance with the performances objective is evaluated using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.1.1 Areas of Review

This section reviews degradation of engineered barriers within the emplacement drift. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(3), (9), (10), (15) and (19), that is relevant to the abstraction of degradation of engineered barriers. It is important to note that the scope of this review includes various parts of the engineered barrier system, as specified in 10 CFR 63.2.

The staff will evaluate the following parts of the abstraction of degradation of engineered barriers, using review methods and acceptance criteria in Sections 4.2.1.3.1.2 and 4.2.1.3.1.3:

- Description of the engineered barrier system, hydrology, geochemistry, and thermal effects related to the degradation of the engineered barrier system and the technical basis the U.S. Department of Energy provides to support model integration, across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare the total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.1.2 Review Methods

To review the abstraction of degradation of engineered barriers, recognize that models used in the total system performance assessments may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the U.S. Department of Energy license application description of design features, physical phenomena, and couplings, as well as the description of the waste package, and features of the engineered barrier system that contribute to high-level radioactive waste isolation. Assess the adequacy of the technical bases for these descriptions and for incorporating them in the total system performance assessment abstraction for the degradation of engineered barriers.

Examine assumptions, technical bases, data, and models used by the U.S. Department of Energy in the total system performance assessment abstraction degradation process models in the total system performance assessment abstraction of the degradation of engineered barriers, for consistency with other related U.S. Department of Energy abstractions. Evaluate whether the descriptions and technical bases provide transparent and traceable support for the abstraction of the degradation of the engineered barriers.

Evaluate whether the U.S. Department of Energy description of aspects of environmental conditions, within the waste package emplacement drifts, design features, physical phenomena, and couplings that may affect the degradation of the engineered barriers, is adequate. Verify that conditions and assumptions, used in the total system performance assessment abstraction of the degradation of the engineered barriers, are consistent with the body of data presented in the abstraction.

Confirm that the U.S. Department of Energy has propagated boundary and initial conditions, used in the total system performance assessment abstraction of the degradation of engineered barriers, throughout its abstraction approaches.

Examine how the features, events, and processes, related to the degradation of the engineered barriers have been included in the total system performance assessment abstraction.

Evaluate the technical bases that the U.S. Department of Energy used for selecting the design criteria, that mitigate any potential impact of in-package criticality on repository performance, including all features, events, and processes that may increase the reactivity of the system inside the waste package; all the configuration classes and configurations that have potential for nuclear criticality; and changes in radionuclide inventory and thermal conditions, in the abstraction of the degradation of engineered barriers.

Verify that the U.S. Department of Energy reviews follow guidance such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the experimental and site characterization data used to support parameters used in conceptual models, process-level models, and alternative conceptual models, considered in the total system performance assessment abstraction of degradation of engineered barriers.

Verify whether sufficient data have been collected to adequately model degradation processes, as well as characteristics of the geochemistry, hydrology, design features, and thermal effects, to establish initial and boundary conditions for the total system performance assessment abstraction of degradation of engineered barriers. For example, mechanical property data should cover the range of anticipated temperatures and microstructural conditions. The corrosion data should consider the appropriate range of environmental conditions, such as chloride concentration.

Evaluate and confirm that data used to support the U.S. Department of Energy total system performance assessment abstraction of the degradation of engineered barriers are based on appropriate techniques, and are adequate for the accompanying sensitivity/uncertainty analyses. Evaluate the need for additional data, based on the sensitivity analyses.

Verify that the U.S. Department of Energy demonstrates the adequacy of the degradation of engineered barriers models used to assess the range of possible degradation processes.

Review Method 3 Data Uncertainty

Evaluate the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions used in conceptual models, process models, and alternative conceptual models, considered in the total system performance assessment abstraction of degradation of engineered barriers. Evaluate the assessment of uncertainty and variability in these parameters, and verify that the technical bases reasonably account for the uncertainties and variabilities in the data.

Examine the abstraction for those degradation processes that the U.S. Department of Energy assumes are not important to performance and confirm that the parameters, used in these abstractions, are assigned values consistent with the abstractions of other degradation processes, determined to be significant to performance of the engineered barriers, as well as the initial and boundary conditions used in other abstractions for the total system performance assessment.

Determine whether the U.S. Department of Energy has used parameters, in the abstraction of the degradation of engineered barriers, that are based on laboratory experiments, field measurements, natural analog or industrial analog research, and process-level modeling studies, conducted under conditions relevant to the range of environmental conditions in the emplacement drifts located in the unsaturated zone at Yucca Mountain. Examine the results of the U.S. Department of Energy engineered barrier degradation tests, and confirm that the U.S. Department of Energy has provided adequate models.

Evaluate the methods used by the U.S. Department of Energy for nondestructive examination of fabricated engineered barriers, including the type, size, and location of fabrication defects, that may lead to premature failure, as a result of rapidly initiated engineered barrier degradation. Examine the justification for the allowable distribution of fabrication defects in the engineered barriers, and evaluate how the U.S. Department of Energy assesses the effect on engineered barrier performance of defects that cannot be detected.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the total system performance assessment abstraction for degradation of engineered barriers. Examine the model parameters in the context of available site characterization data, laboratory corrosion tests, field measurements, and process-level modeling studies.

Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of the degradation of engineered barriers, including waste package corrosion. Examine the effects of the alternative conceptual models on repository performance, and evaluate how model uncertainties are defined, documented and assessed.

Examine the mathematical models used in the analyses of degradation of engineered barriers.

Examine and evaluate the bases for excluding alternative conceptual models and the limitations and uncertainties of the chosen model.

Review Method 5 Model Support

Evaluate the output from the abstraction of the degradation of engineered barriers, and compare the results with a combination of data from laboratory corrosion testing and field measurements, as well as results obtained through process-level modeling. Evaluate the sensitivity analyses used to support the abstraction of the degradation of engineered barriers in the total system performance assessment.

Use detailed models of degradation processes to evaluate the total system performance assessment abstractions of the degradation of engineered barriers. If practical, use an alternative to the total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of the degradation of the engineered barriers, and assess the effects on repository performance. Compare results of the U.S. Department of Energy abstraction to approximations shown to be appropriate for closely analogous systems, industrial experience, and experimental results.

Evaluate evidence to show that models used to evaluate performance are not likely to underestimate the actual degradation and failure of engineered barriers, as a result of corrosion or other degradation processes.

In developing supporting evidence for the models, verify that mathematical models for the degradation of engineered barriers are based on the same environmental parameters, material factors, assumptions, and approximations shown to be appropriate for closely analogous engineering or industrial applications and experimental investigations.

Examine the procedures used by the U.S. Department of Energy to construct and test its mathematical and numerical models.

As appropriate, use an alternative total system performance assessment model to evaluate the U.S. Department of Energy sensitivity or bounding analyses, and confirm that the U.S. Department of Energy has used ranges consistent with available site characterization data, field and laboratory tests, and industrial and natural analog research.

4.2.1.3.1.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the degradation of engineered barriers model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- The total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the degradation of engineered barriers abstraction process;

- Assessment abstraction of the degradation of engineered barriers uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for degradation of engineered barriers should be consistent with the abstractions of the quantity and chemistry of water contacting waste packages and waste forms (Section 4.2.1.3.3); climate and infiltration (Section 4.2.1.3.5); and mechanical disruption of waste packages (Section 4.2.1.3.2). The descriptions and technical bases provide transparent and traceable support for the abstraction of the degradation of engineered barriers;

- The descriptions of engineered barriers, design features, degradation processes, physical phenomena, and couplings that may affect the degradation of the engineered barriers are adequate. For example, materials and methods used to construct the engineered barriers are included, and degradation processes, such as uniform corrosion, pitting corrosion, crevice corrosion, stress corrosion cracking, intergranular corrosion, microbially influenced corrosion, dry-air oxidation, hydrogen embrittlement, and the effects of wet and dry cycles, material aging and phase stability, welding, and initial defects on the degradation modes for the engineered barriers are considered;

- Boundary and initial conditions used in the total system performance assessment abstractions are propagated consistently throughout the abstraction approaches. For example, the conditions and assumptions used in the degradation of engineered barriers abstraction are consistent with those used to model the quantity and chemistry of water contacting waste packages and waste forms (Section 4.2.1.3.3); climate and infiltration (Section 4.2.1.3.5); and mechanical disruption of waste packages (Section 4.2.1.3.2);

- Sufficient technical bases for the inclusion of features, events, and processes related to degradation of engineered barriers in the total system performance assessment abstractions are provided;

- Adequate technical bases are provided, for selecting the design criteria, that mitigate any potential impact of in-package criticality on repository performance, including considering all features, events, and processes that may increase the reactivity of the system inside the waste package. For example, the technical bases for the abstraction of the degradation of engineered barriers include configuration classes and configurations that have potential for nuclear criticality, changes in radionuclide inventory, and changes in thermal conditions; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Parameters used to evaluate the degradation of engineered barriers in the safety case are adequately justified (e.g., laboratory corrosion tests, site-specific data such as data from drift-scale tests, in-service experience in pertinent industrial applications, and test results not specifically performed for the Yucca Mountain site, etc.). The U.S. Department of Energy describes how the data were used, interpreted, and appropriately synthesized into the parameters;

- Sufficient data have been collected on the characteristics of the engineered components, design features, and the natural system to establish initial and boundary conditions for abstraction of degradation of engineered barriers;

- Data on the degradation of the engineered barriers (e.g., general and localized corrosion, microbially influenced corrosion, galvanic interactions, hydrogen embrittlement, and phase stability), used in the abstraction, are based on laboratory measurements, site-specific field measurements, industrial analog and/or natural analog research, and tests designed to replicate the range of conditions that may occur at the Yucca Mountain site. As appropriate, sensitivity or uncertainty analyses, used to support the U.S. Department of Energy total system performance assessment abstraction, are adequate to determine the possible need for additional data; and

- Degradation models for the processes that may be significant to the performance of the engineered barriers are adequate. For example, the U.S. Department of Energy models consider the possible degradation of the engineered barriers, as a result of uniform and localized corrosion processes, stress-corrosion cracking, microbially influenced corrosion, hydrogen embrittlement, and incorporate the effects of fabrication processes, thermal aging, and phase stability.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities;

- For those degradation processes that are significant to the performance of the engineered barriers, the U.S. Department of Energy provides appropriate parameters, based on techniques that may include laboratory experiments, field measurements, industrial analogs, and process-level modeling studies conducted under conditions relevant to the range of environmental conditions within the waste package emplacement drifts. The U.S. Department of Energy also demonstrates the capability to predict the degradation of the engineered barriers in laboratory and field tests;

- For the selection of parameters used in conceptual and process-level models of engineered barrier degradation that can be expected under repository conditions, assumed range of values and probability distributions are not likely to underestimate the actual degradation and failure of engineered barriers as a result of corrosion;

- The U.S. Department of Energy uses appropriate methods for nondestructive examination of fabricated engineered barriers to assess the type, size, and location of fabrication defects that may lead to premature failure as a result of rapidly initiated engineered barrier degradation. The U.S. Department of Energy specifies and justifies the allowable distribution of fabrication defects in the engineered barriers, and assesses the effects of defects that cannot be detected on the performance of the engineered barriers; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models, used by the U.S. Department of Energy, is based on appropriate use of other sources, such as expert elicitation conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- Conceptual model uncertainties are defined and documented, and conclusions regarding performance of the engineered barriers are properly assessed; and

- The U.S. Department of Energy uses alternative modeling approaches, consistent with available data and current scientific understanding, and evaluates the model results and limitations, using tests and analyses that are sensitive to the processes modeled. For example, for processes such as uniform corrosion, localized corrosion, and stress-corrosion cracking of the engineered barriers, the U.S. Department of Energy considers alternative modeling approaches, to develop its understanding of environmental conditions and material factors significant to these degradation processes.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Numerical corrosion models used to calculate the lifetimes of the engineered barriers are adequate representations, considering the associated uncertainties in the expected long-term behaviors, the range of conditions (including residual stresses), and the variability in engineered barrier fabrication processes (including welding);

- Evidence is sufficient to show that models used to evaluate performance are not likely to underestimate the actual degradation and failure of engineered barriers, as a result of corrosion or other degradation processes;

- Mathematical models for the degradation of engineered barriers are based on the same environmental parameters, material factors, assumptions, and approximations shown to be appropriate for closely analogous engineering or industrial applications and experimental investigations;

- Accepted and well-documented procedures are used to construct and test the numerical models that simulate the engineered barrier chemical environment and degradation of engineered barriers; and

- Sensitivity analyses or bounding analyses are provided to support the abstraction of degradation of engineered barriers that cover ranges consistent with the site data, field or laboratory experiments and tests, and industrial analogs.

4.2.1.3.1.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.1.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114, regarding the abstraction of degradation of engineered barriers in the performance assessment. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.1.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.2 Mechanical Disruption of Engineered Barriers

Mechanical disruption of a waste package is defined as partial or total mechanical failure of the waste package resulting from external events (man-made and/or natural), which immediately or eventually reduces its design life and intended performance, and, consequently, causes release of radionuclides. For example, a rock fall may cause a container to rupture or may cause a dent in its structure, which could lead to an accelerated rate of corrosion and failure sooner than under normal conditions.

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which mechanical disruption of engineered barriers affects the U.S. Department of Energy safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on the engineered barriers to provide significant delay in the transport of radionuclides to the reasonably maximally exposed individual, then perform a more detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the delay in the transport of radionuclides to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary in a simplified review for those abstractions that have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.2.1 Areas of Review

This section reviews mechanical disruption of engineered barriers. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1)–(3), (9), (10), (15), and (19), that is relevant to the abstraction of mechanical disruption of engineered barriers.

The staff will evaluate the following parts of the abstraction of mechanical disruption of engineered barriers, using the review methods and acceptance criteria in Sections 4.2.1.3.2.2 and 4.2.1.3.2.3:

- Description of the geological and engineering aspects of mechanical disruption of engineered barriers and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the total system performance assessment;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the total system performance assessment;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.2.2 Review Methods

To review the abstraction of mechanical disruption of engineered barriers, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings included in the mechanical disruption of engineered barriers abstraction. Assess the adequacy of the technical bases for these descriptions and for incorporating them in the total system performance assessment abstraction of mechanical disruption of engineered barriers.

Evaluate whether the description of design features, physical phenomena, and couplings that may affect mechanical disruption of engineered barriers is adequate. Verify that conditions and assumptions, used in the total system performance assessment abstraction of mechanical disruption of engineered barriers, are consistent with the body of data presented in the description.

Examine assumptions, technical bases, data, and models, used by the U.S. Department of Energy in the total system performance assessment abstraction of mechanical disruption of engineered barriers, for consistency with other related U.S. Department of Energy abstractions.

Evaluate whether the descriptions and technical bases provide transparent and traceable support for the abstraction of mechanical disruption of engineered barriers.

Confirm that the U.S. Department of Energy has propagated boundary and initial conditions, used in the total system performance assessment abstraction of mechanical disruption of engineered barriers, throughout its abstraction approaches.

Examine how the features, events, and processes, related to mechanical disruption of engineered barriers, have been included in the total system performance assessment abstraction.

Evaluate the U.S. Department of Energy conclusion with respect to the impact of transient criticality on the integrity of the engineered barriers.

Verify that the U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological and engineering data used to support parameters for conceptual models, process-level models, and alternative conceptual models considered in the abstraction of mechanical disruption of engineered barriers. Evaluate the basis for the data on physical phenomena, couplings, geology, and engineering used in the abstraction of mechanical disruption of engineered barriers. This basis may include a combination of techniques, such as laboratory experiments, site-specific field measurements, natural analog research, process-level modeling studies, and expert elicitation.

Verify that sufficient data have been collected to adequately characterize the geology of the natural system, engineering materials, and initial manufacturing defects to establish initial and boundary conditions for the abstraction of mechanical disruption of engineered barriers.

Evaluate and confirm that data used to support the U.S. Department of Energy abstraction of mechanical disruption of engineered barriers are based on appropriate techniques, and are adequate for the accompanying sensitivity/uncertainty analyses. Evaluate the need for additional data based on sensitivity analyses.

Verify that the U.S. Department of Energy demonstrates the adequacy of engineered barrier mechanical failure models for disruption events.

Review Method 3 Data Uncertainty

Evaluate the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions, used in conceptual models, process-level models, and alternative conceptual models, considered in the abstraction of mechanical disruption of engineered barriers. Evaluate the assessment of uncertainty and variability in these parameters, and verify that the technical bases reasonably account for uncertainties and variabilities in the data.

Evaluate the U.S. Department of Energy justification of process-level models used to represent mechanically disruptive events within the emplacement drifts at the proposed Yucca Mountain repository. Verify that the U.S. Department of Energy parameter values are adequately constrained by Yucca Mountain site data, such that the effects of mechanically disruptive events on engineered barrier integrity are not underestimated. Confirm that the U.S. Department of Energy identifies parameters within conceptual models for mechanically disruptive events that are consistent with the range of characteristics observed at Yucca Mountain.

Assess how uncertainty is represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of mechanical disruption of engineered barriers.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the abstraction for mechanical disruption of engineered barriers. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies and evaluate their consistency.

Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of mechanical disruption of engineered barriers. Examine the effects of the alternative conceptual model(s) on repository performance, and evaluate how model uncertainties are defined, documented, and assessed.

Examine the mathematical models included in the analyses of mechanical disruption of engineered barriers. Also, examine and evaluate the bases for excluding alternative conceptual models, and the limitations and uncertainties of the chosen model.

Review Method 5 Model Support

Evaluate the output from the abstraction of mechanical disruption of engineered barriers, and compare the results with an appropriate combination of site characterization data, process-level modeling, laboratory testing, field measurements, and natural analog research.

Use detailed models of geological and engineering processes to evaluate the total system performance assessment abstractions of mechanical disruption of engineered barriers. If practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of mechanical disruption of engineered barriers, and evaluate the effects on repository performance. Compare results of the U.S. Department of Energy abstraction to approximations shown to be appropriate for closely analogous natural systems or experimental systems.

Examine the procedures used by the U.S. Department of Energy to develop and test its mathematical and numerical models.

As appropriate, use an alternative total system performance assessment model to evaluate the U.S. Department of Energy sensitivity or bounding analyses, and confirm that the U.S. Department of Energy has used ranges consistent with available site characterization data, field and laboratory tests, and natural analog research.

4.2.1.3.2.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the mechanical disruption of engineered barriers model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the mechanical disruption of engineered barrier abstraction process;

- The description of geological and engineering aspects of design features, physical phenomena, and couplings, that may affect mechanical disruption of engineered barriers, is adequate. For example, the description may include materials used in the construction of engineered barrier components, environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) on these materials, and mechanical-failure processes and concomitant failure criteria used to assess the performance capabilities of these materials. Conditions and assumptions in the abstraction of mechanical disruption of engineered barriers are readily identified and consistent with the body of data presented in the description;

- The abstraction of mechanical disruption of engineered barriers uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, assumptions used for mechanical disruption of engineered barriers are consistent with the abstraction of degradation of engineered barriers (Section 4.2.1.3.1 of the Yucca Mountain Review Plan). The descriptions and technical bases provide transparent and traceable support for the abstraction of mechanical disruption of engineered barriers;

- Boundary and initial conditions used in the total system performance assessment abstraction of mechanical disruption of engineered barriers are propagated throughout its abstraction approaches;

- Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided;

- The conclusion, with respect to the impact of transient criticality on the integrity of the engineered barriers, is defensible; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Geological and engineering values, used in the safety case to evaluate mechanical disruption of engineered barriers, are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;

- Sufficient data have been collected on the geology of the natural system, engineering materials, and initial manufacturing defects, to establish initial and boundary conditions for the total system performance assessment abstraction of mechanical disruption of engineered barriers;

- Data on geology of the natural system, engineering materials, and initial manufacturing defects, used in the total system performance assessment abstraction, are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the U.S. Department of Energy total system performance assessment abstraction are adequate to determine the possible need for additional data; and

- Engineered barrier mechanical failure models for disruption events are adequate. For example, these models may consider effects of prolonged exposure to the expected emplacement drift environment, material test results not specifically designed or performed for the Yucca Mountain site, and engineered barrier component fabrication flaws.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities;

- Process-level models used to represent mechanically disruptive events, within the emplacement drifts at the proposed Yucca Mountain repository, are adequate. Parameter values are adequately constrained by Yucca Mountain site data, such that the effects of mechanically disruptive events on engineered barrier integrity are not underestimated. Parameters within conceptual models for mechanically disruptive events are consistent with the range of characteristics observed at Yucca Mountain;

- Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the assessment abstraction of mechanical disruption of engineered barriers. This may be done either through sensitivity analyses or use of conservative limits; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed; and

- Appropriate alternative modeling approaches are investigated that are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations using tests and analyses that are sensitive to the processes modeled.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Outputs of mechanical disruption of engineered barrier abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both;

- Well-documented procedures, that have been accepted by the scientific community to construct and test the mathematical and numerical models, are used to simulate mechanical disruption of engineered barriers; and

- Sensitivity analyses or bounding analyses are provided to support the total system performance assessment abstraction of mechanical disruption of engineered barriers that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.

4.2.1.3.2.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.2.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114, regarding the abstraction of mechanical disruption of engineered barriers in the performance assessment. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.2.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.3 Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the quantity and chemistry of water contacting waste packages and waste forms affect the U.S. Department of Energy safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on the processes affecting the quantity and chemistry of water contacting waste packages and waste forms to significantly reduce dose to the reasonably maximally exposed individual, then a detailed review of this abstraction will be performed. If, on the other hand, the U.S. Department of Energy demonstrates that this abstraction has a minor impact on the dose to the reasonably maximally exposed individual, then a simplified review will be conducted focusing on the

bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of the performance objectives is evaluated in Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.3.1 Areas of Review

This section reviews quantity and chemistry of water contacting waste packages and waste forms. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1)–(4), (9), (10), (15), and (19), that is relevant to the abstraction of quantity and chemistry of water contacting waste packages and waste forms.

The staff will evaluate the following parts of the abstraction of quantity and chemistry of water contacting waste packages and waste forms, using the review methods and acceptance criteria in Sections 4.2.1.3.3.2 and 4.2.1.3.3.3:

- Description of the geological, hydrological, and geochemical aspects of quantity and chemistry of water contacting waste packages and waste forms, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.3.2 Review Methods

To review the abstraction of quantity and chemistry of water contacting waste packages and waste forms, recognize that models used in the total system performance assessments may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy regardless of the level of complexity.

Review Method 1 Model Integration

Examine the descriptions of design features (including drip shield, backfill, waste packages, drift design and support, thermal loading, and other engineered barrier components); relevant physical features; physical phenomena; and couplings, as well as the description of the geological, hydrological, geochemical, and geomechanical aspects of the unsaturated zone, included in the abstraction of quantity and chemistry of water contacting waste packages and waste forms. Assess the adequacy of the technical bases for these descriptions, and for incorporating them in the total system performance assessment to represent quantity and chemistry of water contacting waste packages and waste forms.

Evaluate whether the description of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect the quantity and chemistry of water contacting waste packages and waste forms, is adequate. Verify that conditions, assumptions, and the technical bases, used in the abstraction of quantity and chemistry of water contacting waste packages and waste forms, are consistent with other related U.S. Department of Energy abstractions.

Verify that important design features, such as waste package design and material selection, backfill, drip shield, ground support, thermal loading strategy, and degradation processes, are included in determining the initial and boundary conditions for calculations of the quantity and chemistry of water contacting waste packages and waste forms.

Examine the spatial and temporal abstractions to determine whether they appropriately address the physical couplings (thermal-hydrologic-mechanical-chemical).

Assess the technical bases for the geological, hydrological, geochemical, and geomechanical descriptions, and for incorporating them in the total system performance assessment abstraction for coupled thermal-hydrologic-mechanical-chemical effects. Determine whether the technical bases used for modeling assumptions and approximations have been documented, and are adequate. Evaluate whether the descriptions provide transparent and traceable support to the abstraction, and are consistent with other model abstractions.

Evaluate the model abstraction for quantity and chemistry of water contacting waste packages and waste forms, to ensure that it reasonably bounds the expected ranges of environmental conditions within the waste package emplacement drifts, inside of breached waste packages, and contacting the waste forms.

Evaluate the consistency of the model abstraction for quantity and chemistry of water contacting waste packages and waste forms with detailed information on waste package design and other engineered features.

Examine how the features, events, and processes, related to the quantity and chemistry of water contacting waste packages and waste forms have been included in the total system performance assessment abstraction.

Determine whether processes that have been observed in thermal-hydrologic tests and experiments and that are significant to performance are included in the total system performance assessment model abstraction.

Ensure that the U.S. Department of Energy includes likely modes for container corrosion (Section 4.2.1.3.1 of the Yucca Mountain Review Plan) in determining the quantity and chemistry of water entering the waste packages and contacting waste forms. Evaluate the treatment of parameters such as pH and carbonate concentration, and the effect of waste package corrosion on the quantity and chemistry of water contacting waste packages and waste forms.

Evaluate the abstraction of in-package criticality or external-to-package criticality within the emplacement drift, and the associated technical basis for screening these events. Ensure that if either event is included in the total system performance assessment, the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of the quantity and chemistry of water contacting waste packages and waste forms.

Verify that the U.S. Department of Energy reviews follow the guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, hydrological, and geochemical data used to support parameters used in conceptual models, process-level models, and alternative conceptual models (if any) considered in the abstraction of quantity and chemistry of water contacting waste packages and waste forms. Evaluate whether the basis for the data includes a combination of techniques, such as laboratory experiments, site-specific field measurements, natural analog research, process-level modeling studies, and expert elicitation. Assess how the data were used, interpreted, and synthesized into the parameters. Examine and confirm the sufficiency, transparency, and traceability of the data that support the technical bases for features, events, and processes, related to the quantity and chemistry of water contacting waste packages and waste forms, that have been included in the total system performance assessment abstraction.

Verify that sufficient data were collected on the characteristics of the natural system and engineered materials to establish initial and boundary conditions for conceptual models of thermal-hydrologic-mechanical-chemical coupled processes that affect seepage and flow and the waste package chemical environment, and the chemical environment for radionuclide release.

Ensure that the U.S. Department of Energy has used results from thermal-hydrologic tests to identify important processes and establish temperature ranges for repository conditions in

developing its mathematical models. Verify that the data are sufficient to support thermal-hydrologic conceptual models.

Evaluate the sufficiency of data used to support the conceptual approaches for water contact with the drip shield, waste package, and waste forms.

Examine the sufficiency of data used to support the analysis of the potential for microbial activity affecting the waste package chemical environment and the chemical environment for radionuclide release. Ensure that the data are sufficient to constrain the probability for microbially influenced corrosion and microbially enhanced dissolution of the high-level radioactive waste glass form.

Review Method 3 Data Uncertainty

Evaluate the sufficiency of the technical bases for parameter values and ranges used in conceptual models, process-level models, and alternative conceptual models considered in the total system performance assessment abstraction. Determine whether the U.S. Department of Energy has reasonably accounted for uncertainties and variabilities in developing parameter values and ranges.

Determine whether the parameter values are based on site-specific data obtained from techniques such as laboratory and field experiments. As necessary, evaluate whether the parameter values and ranges derived from natural analog research or process-level models are correctly incorporated in the model abstraction of quantity and chemistry of water contacting waste packages and waste forms.

Evaluate the initial and boundary conditions used to evaluate coupled thermal-hydrologic-mechanical-chemical effects on the quantity and chemistry of water contacting waste packages and waste forms for consistency with available data. As necessary, confirm that correlations between input values have been appropriately established in the U.S. Department of Energy total system performance assessment.

Evaluate the U.S. Department of Energy assessment of uncertainty and variability in parameters. Determine whether the U.S. Department of Energy incorporates data uncertainty and temporal and spatial variability in conditions affecting coupled thermal-hydrologic-mechanical-chemical effects into parameter ranges.

If in-package criticality or external-to-package criticality is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor.

If expert elicitations were used as a basis for data uncertainty for this abstraction, confirm they were conducted in accordance with appropriate guidance (Kotra, et al., 1996).

Review Method 4 Model Uncertainty

Determine whether the U.S. Department of Energy has considered appropriate alternative conceptual models. Examine the bases for alternative conceptual models, considered in the

model abstraction of quantity and chemistry of water contacting waste packages and waste forms, and the limitations and uncertainties of the chosen model. Evaluate the discussion of alternative modeling approaches not considered in the final analysis, and the limitations and uncertainties of the chosen model. Evaluate the selected model for consistency with available data.

Evaluate the U.S. Department of Energy assessment of the effects of model uncertainty on conclusions regarding performance.

Review the methods used by the U.S. Department of Energy in considering the effects of thermal-hydrologic-mechanical-chemical coupled processes in different alternative conceptual models.

Determine whether the U.S. Department of Energy has provided an adequate demonstration of the effects on radiological exposures to the reasonably maximally exposed individual and releases of radionuclides into the accessible environment in its assessment of alternative conceptual models of coupled thermal-hydrologic-mechanical-chemical processes.

Review Method 5 Model Support

Evaluate the output from the abstraction of the quantity and chemistry of water contacting waste packages and waste forms, and compare the results with an appropriate combination of site characterization and design data, process-level modeling, laboratory testing, field measurements, and natural analog data.

Examine the analytical and numerical models used in the thermal-mechanical analyses for consistency with site-specific or natural analog data. Evaluate predicted changes in hydrologic properties and the magnitudes and distributions of changes resulting from effects of thermal-mechanical processes, for consistency with results of thermal-mechanical analyses of the underground facility.

Examine the output from the mathematical models for abstractions of coupled-process effects on the quantity and chemistry of water contacting waste packages and waste forms for consistency with conceptual models, based on inferences about the near-field environment, field data, and natural alteration observed at the site, and expected engineered materials properties. Examine the use of abstracted model results, and compare mathematical models to judge the robustness of results. Evaluate the acceptability of the sensitivity analyses used to support the abstraction of the quantity and chemistry of water contacting waste packages and waste forms in the total system performance assessment. To the extent practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction, and to evaluate the effects of the quantity and chemistry of water contacting waste packages and waste forms on repository performance.

4.2.1.3.3.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the quantity and chemistry of water contacting waste packages and waste forms model abstraction. U.S. Nuclear Regulatory Commission

staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the quantity and chemistry of water contacting waste packages and waste forms abstraction process;

- The abstraction of the quantity and chemistry of water contacting waste packages and waste forms uses assumptions, technical bases, data, and models, that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for the quantity and chemistry of water contacting waste packages and waste forms are consistent with the abstractions of "Degradation of Engineered Barriers" (Section 4.2.1.3.1); "Mechanical Disruption of Waste Packages" (Section 4.2.1.3.2); "Radionuclide Release Rates and Solubility Limits" (Section 4.2.1.3.4); "Climate and Infiltration" (Section 4.2.1.3.5); and "Flow Paths in the Unsaturated Zone" (Section 4.2.1.3.6). The descriptions and technical bases provide transparent and traceable support for the abstraction of quantity and chemistry of water contacting waste packages and waste forms;

- Important design features, such as waste package design and material selection, backfill, drip shield, ground support, thermal loading strategy, and degradation processes, are adequate to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting waste packages and waste forms;

- Spatial and temporal abstractions appropriately address physical couplings (thermal-hydrologic-mechanical-chemical). For example, the U.S. Department of Energy evaluates the potential for focusing of water flow into drifts, caused by coupled thermal-hydrologic-mechanical-chemical processes;

- Sufficient technical bases and justification are provided for total system performance assessment assumptions and approximations for modeling coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow, the waste package chemical environment, and the chemical environment for radionuclide release. The effects of distribution of flow on the amount of water contacting the waste packages and waste forms are consistently addressed, in all relevant abstractions;

- The expected ranges of environmental conditions within the waste package emplacement drifts, inside of breached waste packages, and contacting the waste forms and their evolution with time are identified. These ranges may be developed to include: (i) the effects of the drip shield and backfill on the quantity and chemistry of water (e.g., the potential for condensate formation and dripping from the underside of the shield); (ii) conditions that promote corrosion of engineered barriers and degradation of waste forms; (iii) irregular wet and dry cycles; (iv) gamma-radiolysis; and (v) size and distribution of penetrations of waste packages;

- The model abstraction for quantity and chemistry of water contacting waste packages and waste forms is consistent with the detailed information on waste package design and other engineered features. For example, consistency is demonstrated for: (i) dimensionality of the abstractions; (ii) various design features and site characteristics; and (iii) alternative conceptual approaches. Analyses are adequate to demonstrate that no deleterious effects are caused by design or site features that the U.S. Department of Energy does not take into account in this abstraction;

- Adequate technical bases are provided, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for inclusion of any thermal-hydrologic-mechanical-chemical couplings and features, events, and processes;

- Performance-affecting processes that have been observed in thermal-hydrologic tests and experiments are included into the performance assessment. For example, the U.S. Department of Energy either demonstrates that liquid water will not reflux into the underground facility or incorporates refluxing water into the performance assessment calculation, and bounds the potential adverse effects of alteration of the hydraulic pathway that result from refluxing water;

- Likely modes for container corrosion (Section 4.2.1.3.1 of the Yucca Mountain Review Plan) are identified and considered in determining the quantity and chemistry of water entering the waste packages and contacting waste forms. For example, the model abstractions consistently address the role of parameters, such as pH, carbonate concentration, and the effect of waste package corrosion on the quantity and chemistry of water contacting waste packages and waste forms;

- The abstraction of in-package criticality or external-to-package criticality, within the emplacement drift, provides an adequate technical basis for screening these events. If either event is included in the assessment, then the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of the quantity and chemistry of water contacting waste packages and waste forms; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches, is followed.

Acceptance Criterion 2 Data are Sufficient for Model Justification.

- Geological, hydrological, and geochemical values used in the safety case are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided;

- Sufficient data were collected on the characteristics of the natural system and engineered materials to establish initial and boundary conditions for conceptual models

of thermal-hydrologic-mechanical-chemical coupled processes, that affect seepage and flow and the waste package chemical environment;

- Thermo-hydrologic tests were designed and conducted with the explicit objectives of observing thermal-hydrologic processes for the temperature ranges expected for repository conditions and making measurements for mathematical models. Data are sufficient to verify that thermal-hydrologic conceptual models address important thermal-hydrologic phenomena;

- Sufficient information to formulate the conceptual approach(es) for analyzing water contact with the drip shield, waste package, and waste forms is provided; and

- Sufficient data are provided to complete a nutrient- and energy-inventory calculation, if it has been used to justify the inclusion of the potential for microbial activity affecting the waste package chemical environment and the chemical environment for radionuclide release. As necessary, data are adequate to constrain the probability for microbially influenced corrosion and microbial effects, such as production of organic byproducts and microbially enhanced dissolution of the high-level radioactive waste glass form.

Acceptance Criterion 3 Data Uncertainty is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;

- Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the total system performance assessment calculations of quantity and chemistry of water contacting waste packages and waste forms are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large block and drift-scale heater and niche tests), and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies;

- Input values used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers (e.g., drip shield and waste package) are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the Yucca Mountain site. Correlations between input values are appropriately established in the U.S. Department of Energy total system performance assessment. Parameters used to define initial conditions, boundary conditions, and computational domain in sensitivity analyses involving coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow, the waste package chemical environment, and the chemical environment for radionuclide release, are consistent with available data. Reasonable or conservative ranges of parameters or functional relations are established;

- Adequate representation of uncertainties in the characteristics of the natural system and engineered materials is provided in parameter development for conceptual models,

process-level models, and alternative conceptual models. The U.S. Department of Energy may constrain these uncertainties using sensitivity analyses or conservative limits. For example, the U.S. Department of Energy demonstrates how parameters used to describe flow through the engineered barrier system bound the effects of backfill and excavation-induced changes;

- If criticality is included in the total system performance assessment, then the U.S. Department of Energy uses an appropriate range of input parameters for calculating the effective neutron multiplication factor; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on other appropriate sources, such as expert elicitation conducted in accordance with NUREG–1563 (Kotra, et al., 1996).

Acceptance Criterion 4 Model Uncertainty is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- Alternative modeling approaches are considered and the selected modeling approach is consistent with available data and current scientific understanding. A description that includes a discussion of alternative modeling approaches not considered in the final analysis and the limitations and uncertainties of the chosen model is provided;

- Adequate consideration is given to effects of thermal-hydrologic-mechanical-chemical coupled processes in the assessment of alternative conceptual models. These effects may include: (i) thermal-hydrologic effects on gas, water, and mineral chemistry; (ii) effects of microbial processes on the waste package chemical environment and the chemical environment for radionuclide release; (iii) changes in water chemistry that may result from the release of corrosion products from the waste package and interactions between engineered materials and ground water; and (iv) changes in boundary conditions (e.g., drift shape and size) and hydrologic properties, relating to the response of the geomechanical system to thermal loading; and

- If the U.S. Department of Energy uses an equivalent continuum model for the total system performance assessment abstraction, the models produce conservative estimates of the effects of coupled thermal-hydrologic-mechanical-chemical processes on calculated compliance with the postclosure public health and environmental standards.

Acceptance Criterion 5 Model Abstraction Output is Supported by Objective Comparisons.

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Abstracted models for coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow and the waste package chemical environment, as well as on the chemical environment for radionuclide release, are based on the same assumptions and approximations demonstrated to be appropriate for process-level models or closely analogous natural or experimental systems. For example, abstractions of processes, such as thermally induced changes in hydrological properties, or estimated diversion of percolation away from the drifts, are adequately justified by comparison to results of process-level modeling, that are consistent with direct observations and field studies; and

- Accepted and well-documented procedures are used to construct and test the numerical models that simulate coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow, waste package chemical environment, and the chemical environment for radionuclide release. Analytical and numerical models are appropriately supported. Abstracted model results are compared with different mathematical models, to judge robustness of results.

4.2.1.3.3.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.3.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to the quantity and chemistry of water contacting waste packages and waste forms, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for this abstraction. Technical requirements for conducting a performance assessment in the area of quantity and chemistry of water contacting waste packages and waste forms have been met. In particular, the U.S. Nuclear Regulatory Commission staff that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.3.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.4 Radionuclide Release Rates and Solubility Limits

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on radionuclide release rates and solubility limits, to demonstrate its safety case. Review this model abstraction considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy safety case relies on the release rates and solubility limits to significantly reduce dose to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates that this abstraction has a minor impact on the dose to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have minor impacts on performance. The demonstration of the performance objectives is evaluated in Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.4.1 Areas of Review

This section reviews radionuclide release rates and solubility limits. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1)–(4), (9), (10), (15), and (19), that is relevant to the abstraction of radionuclide release rates and solubility limits.

The staff will evaluate the following parts of the abstraction of radionuclide release rates and solubility limits using the review methods and acceptance criteria in Sections 4.2.1.3.4.2 and 4.2.1.3.4.3:

- Description of the geological, hydrological, and geochemical aspects of radionuclide release rates and solubility limits, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output model abstraction to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.4.2 Review Methods

To review the abstraction of radionuclide release rates and solubility limits, recognize that models used in the total system performance assessments may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the descriptions of design features (including drip shield, backfill, waste packages, waste forms, thermal loading, and other engineered barrier components); relevant physical features; physical phenomena; and couplings, as well as the description of the geological, hydrological, and geochemical aspects of the unsaturated zone included in the abstraction of radionuclide release rates and solubility limits. Verify that the description is adequate, and that the conditions and assumptions in the total system performance assessment abstraction are consistent with the information presented in the description of barriers important to waste isolation, as reviewed using Section 4.2.1.1 of the Yucca Mountain Review Plan.

Assess the technical bases for these descriptions and for incorporating them in the total system performance assessment abstractions. Where simplifications for modeling coupled thermal-hydrologic-chemical effects on the chemical environment for radionuclide release rates and solubility limits were used in the total system performance assessment abstractions, determine

whether the technical bases used for modeling assumptions and approximations have been documented and are adequate. Evaluate whether the descriptions provide transparent and traceable support to the abstractions, and are consistent with other model abstractions.

Evaluate the design information on waste packages and engineered barrier systems, provided in the abstraction of radionuclide release rates and solubility limits. Verify that the information is sufficient and consistent with design information in other model abstractions.

Examine the U.S. Department of Energy description of environmental conditions expected inside breached waste packages and in the engineered barrier environment surrounding the waste package. Ensure that the ranges in conditions are described in sufficient detail.

Verify that the U.S. Department of Energy description of process-level conceptual and mathematical models is sufficiently complete, with respect to thermal-hydrologic processes affecting radionuclide release from the emplacement drifts.

Examine how the features, events, and processes related to radionuclide release rates and solubility limits have been included in the total system performance assessment abstraction of radionuclide release rates and solubility limits.

Evaluate the total system performance assessment abstraction of in-package criticality or external-to-package criticality, within the emplacement drift, and the associated technical basis for screening these events. Ensure that if either event is included in the total system performance assessment, the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on the repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of radionuclide release rates and solubility limits.

Verify that the U.S. Department of Energy reviews follow the guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, hydrological, and geochemical data used to support conceptual models, process-level models, and alternative conceptual models considered in the abstraction of radionuclide release rates and solubility limits. Evaluate the basis for the data on design features (including drip shield, backfill, waste packages, waste forms, and other engineered barrier components) used in the abstraction of radionuclide release rates and solubility limits.

Examine and confirm that the U.S. Department of Energy has provided sufficient data on the characteristics of the natural system, and engineered materials to establish initial and boundary conditions for conceptual models and simulations of thermal-hydrologic-chemical coupled processes.

Examine and evaluate the models used to support abstraction of solubility limits, and ensure that they are consistent with guidance in "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation, Technical Position" (U.S. Nuclear Regulatory Commission, 1984).

Evaluate the U.S. Department of Energy corrosion and radionuclide release testing program for high-level radioactive waste forms intended for disposal. Verify that it provides consistent, sufficient, and suitable data for the in-package and in-drift chemistry, used in the abstraction of radionuclide release rates and solubility limits. Evaluate the justification for the use of test results not specifically collected from the Yucca Mountain site.

Review Method 3 Data Uncertainty

Evaluate whether the U.S. Department of Energy has developed parameter ranges, probability distributions, and bounding values that adequately account for data uncertainty and variability.

Evaluate the technical bases for parameter ranges, probability distributions, or bounding values. The reviewer should determine whether the parameter values are derived from site-specific data, or an analysis is included to show that the assumed parameter values lead to a conservative assessment of performance. Examine the technical bases for parameter values and ranges in conceptual models, process-level models, and alternative conceptual models considered in the abstraction.

Examine the initial conditions, boundary conditions, and computational domain used in sensitivity analyses, involving coupled thermal-hydrologic-chemical effects on radionuclide release, for consistency with available data.

Evaluate the U.S. Department of Energy assessment of uncertainty and variability in parameters used in model abstractions. Determine whether uncertainty in data from both temporal and spatial variations in conditions affecting radionuclide release, was incorporated into the parameter ranges.

Evaluate the parameters used to describe flow through and out of the engineered barrier, and ensure that they are sufficient to bound the effects of backfill, excavation-induced changes, and thermally induced mechanical changes that affect flow.

If in-package criticality or external-to-package criticality is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor.

Verify that the U.S. Department of Energy uses an appropriate range of time-history of temperature, humidity, and dripping to constrain the probability for microbial effects.

Ensure that the U.S. Department of Energy adequately considers the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of thermal-hydrologic-chemical coupled processes that affect radionuclide release.

Determine whether expert elicitations were used as a basis for data uncertainty for this abstraction, and whether they were conducted in accordance with appropriate guidance.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the total system performance assessment abstraction for radionuclide release rates and solubility limits. Examine the model parameters in the context of available site characterization data; design data (engineered barrier system, waste packages, and waste forms); laboratory experiments; field measurements; natural analog research; and process-level modeling studies. When practical, use an alternative total system performance assessment model to evaluate the effect of alternative conceptual models on the assessment of repository performance.

Ensure that the U.S. Department of Energy uses appropriate models, tests, and analyses that are sensitive to the processes modeled for both natural and engineering systems. Verify that conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed.

Examine the mathematical models included in the analyses of coupled thermal-hydrologic-chemical effects on the chemical environment for radionuclide release. Evaluate the bases for excluding alternative conceptual models, and the limitations and uncertainties of the chosen model.

Review Method 5 Model Support

Evaluate the output from the abstraction of radionuclide release rates and solubility limits, and ensure that the U.S. Department of Energy has compared the results with an appropriate combination of site characterization and design data, process-level modeling, laboratory testing, field measurements, and natural analog data.

Examine the analytical and numerical models used in the thermal-mechanical analyses for consistency with site-specific or natural analog data. Evaluate predicted changes in hydrologic properties and the magnitudes and distributions of changes resulting from effects of thermal-mechanical processes for consistency with results of thermal-mechanical analyses of the underground facility. To the extent practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction, and to evaluate the effects of the quantity and chemistry of water contacting the waste packages and waste forms on repository performance.

Examine the output from the mathematical models for abstractions of coupled-process effects on radionuclide release for consistency with conceptual models. Compare the output from the abstractions with inferences about the near-field environment, field data, and natural alteration observed at the site, and expected engineered materials properties.

Evaluate where the U.S. Department of Energy will rely on performance confirmation for this model abstraction, and whether specific plans for monitoring radionuclide release are adequate for further testing, to acquire additional necessary information, as part of the performance confirmation program, using Section 4.4 of the Yucca Mountain Review Plan.

4.2.1.3.4.3 Acceptance Criteria

The following acceptance criteria are based on meeting the relevant requirements of 10 CFR 63.114(a)–(c) and (e)–(g), as they relate to the radionuclide release rates and solubility limits model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the radionuclide release rates and solubility limits abstraction process;

- The abstraction of radionuclide release rates and solubility limits uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for this model abstraction are consistent with the abstractions of "Degradation of Engineered Barriers" (Section 4.2.1.3.1); "Mechanical Disruption of Waste Packages" (Section 4.2.1.3.2); Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms" (Section 4.2.1.3.3); "Climate and Infiltration" (Section 4.2.1.3.5); and "Flow Paths in the Unsaturated Zone" (Section 4.2.1.3.6). The descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide release rates and solubility limits;

- The abstraction of radionuclide release rates and solubility limits provides sufficient, consistent design information on waste packages and engineered barrier systems. For example, inventory calculations and selected radionuclides are based on the detailed information provided on the distribution (both spatially and by compositional phase) of the radionuclide inventory, within the various types of high-level radioactive waste;

- The U.S. Department of Energy reasonably accounts for the range of environmental conditions expected inside breached waste packages and in the engineered barrier environment surrounding the waste package. For example, the U.S. Department of Energy should provide a description and sufficient technical bases for its abstraction of changes in hydrologic properties in the near field, caused by coupled thermal-hydrologic-mechanical-chemical processes;

- The description of process-level conceptual and mathematical models is sufficiently complete, with respect to thermal-hydrologic processes affecting radionuclide release from the emplacement drifts. For example, if the U.S. Department of Energy uncouples coupled processes, the demonstration that uncoupled model results bound predictions of fully coupled results is adequate;

- Technical bases for inclusion of any thermal-hydrologic-mechanical-chemical couplings and features, events, and processes in the radionuclide release rates and solubility

limits model abstraction are adequate. For example, technical bases may include activities, such as independent modeling, laboratory or field data, or sensitivity studies;

- The abstraction of in-package criticality or external-to-package criticality, within the emplacement drift, provides an adequate technical basis for screening these events. If either event is included in the total system performance assessment, then the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on the repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of radionuclide release rates and solubility limits; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer reviews and data qualification, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Geological, hydrological, and geochemical values used in the safety case are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided;

- Sufficient data have been collected on the characteristics of the natural system and engineered materials to establish initial and boundary conditions for conceptual models and simulations of thermal-hydrologic-chemical coupled processes. For example,

  sufficient data should be provided on design features, such as the type, quantity, and reactivity of materials, that may affect radionuclide release for this abstraction;

- Where the U.S. Department of Energy uses data supplemented by models to support abstraction of solubility limits, the anticipated range of proportions and compositions of phases under the various physicochemical conditions expected are supported by experimental data (U.S. Nuclear Regulatory Commission, 1984); and

- The corrosion and radionuclide release testing program for high-level radioactive waste forms intended for disposal provides consistent, sufficient, and suitable data for the in-package and in-drift chemistry used in the abstraction of radionuclide release rates and solubility limits. For expected environmental conditions, the U.S. Department of Energy provides sufficient justification for the use of test results, not specifically collected from the Yucca Mountain site, for engineered barrier components, such as high-level radioactive waste forms, drip shield, and backfill.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;

- Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstractions of radionuclide release rates and solubility limits in the total system performance assessment are technically defensible and reasonable based on data from the Yucca Mountain region, laboratory tests, and natural analogs. For example, parameter values, assumed ranges, probability distributions, and bounding assumptions adequately reflect the range of environmental conditions expected inside breached waste packages;

- The U.S. Department of Energy uses reasonable or conservative ranges of parameters or functional relations to determine effects of coupled thermal-hydrologic-chemical processes on radionuclide release. These values are consistent with the initial and boundary conditions and the assumptions for the conceptual models and design concepts for natural and engineered barriers at the Yucca Mountain site. If any correlations between the input values exist, they are adequately established in the total system performance assessment. For example, estimations are based on a thermal loading and ventilation strategy; engineered barrier system design (including drift liner, backfill, and drip-shield); and natural system masses and fluxes that are consistent with those used in other abstractions;

- Uncertainty is adequately represented in parameter development for conceptual models, process models, and alternative conceptual models considered in developing the abstraction of radionuclide release rates and solubility limits, either through sensitivity analyses or use of bounding analyses;

- Parameters used to describe flow through and out of the engineered barrier, sufficiently bound the effects of backfill, excavation-induced changes, and thermally induced mechanical changes that affect flow;

- If criticality cannot be excluded from total system performance assessment, then the U.S. Department of Energy provides an appropriate range of input parameters for calculating the effective neutron multiplication factor;

- The U.S. Department of Energy uses an appropriate range of time-history of temperature, humidity, and dripping to constrain the probability for microbial effects, such as production of organic by-products that act as complexing ligands for actinides and microbially enhanced dissolution of the high-level radioactive waste glass form;

- The U.S. Department of Energy adequately considers the uncertainties, in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for

conceptual models and simulations of thermal-hydrologic-chemical coupled processes that affect radionuclide release; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate other sources, such as expert elicitation conducted in accordance with NUREG–1563 (Kotra, et al., 1996).

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- In considering alternative conceptual models for radionuclide release rates and solubility limits, the U.S. Department of Energy uses appropriate models, tests, and analyses that are sensitive to the processes modeled for both natural and engineering systems. Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed. For example, in modeling flow and radionuclide release from the drifts, the U.S. Department of Energy represents significant discrete features, such as fault zones, separately, or demonstrates that their inclusion in the equivalent continuum model produces a conservative effect on calculated performance; and
- The effects of thermal-hydrologic-chemical coupled processes that may occur in the natural setting, or from interactions with engineered materials, or their alteration products, on radionuclide release, are appropriately considered.

Acceptance Criterion 5 Model Abstraction Output is Supported by Objective Comparisons.

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Results of thermal-hydrologic process-level models are verified by demonstrating consistency with observations and results from laboratory and field-scale thermal-hydrologic tests. In particular, the U.S. Department of Energy demonstrates that sufficient physical evidence exists, to support conceptual models used to predict thermally driven flow in the near field;

- The U.S. Department of Energy adopts well-documented procedures that have been accepted by the scientific community to construct and test the numerical models, used to simulate coupled thermal-hydrologic-chemical effects on radionuclide release. For example, the U.S. Department of Energy demonstrates that the numerical models used for high-level radioactive waste degradation and dissolution, and radionuclide release from the engineered barrier system, are adequate representations; include consideration of uncertainties; and are not likely to underestimate radiological exposures

to the reasonably maximally exposed individual and releases of radionuclides into the accessible environment; and

- If the U.S. Department of Energy will rely on the performance confirmation program to assess whether the natural system and engineered materials are functioning as intended, an adequate program for monitoring radionuclide release from the waste packages, during the performance confirmation period, is established, using assumptions and calculations of radionuclide release from the waste packages that are appropriately substantiated (the acceptability of the performance confirmation program is reviewed using Section 4.4 of the Yucca Mountain Review Plan).

4.2.1.3.4.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.4.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to radionuclide release rates and solubility limits, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment in the area of radionuclide release rates and solubility limits have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.4.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

U.S. Nuclear Regulatory Commission. "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation, Technical Position." Washington, DC: U.S. Nuclear Regulatory Commission. 1984.

4.2.1.3.5 Climate and Infiltration

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on climate and infiltration to demonstrate its safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on climate and infiltration to provide significant delay in the transport of radionuclides or a significant dilution in dose to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the delay in the transport of radionuclides to the reasonably maximally exposed individual, or insignificant dilution in dose, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary in a simplified review for those abstractions that have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.5.1 Areas of Review

This section reviews climate and net infiltration. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9)(10), (15), and (19), that is relevant to the abstraction of climate and infiltration.

The staff will evaluate the following parts of the abstraction of climate and infiltration, using the review methods and acceptance criteria in Sections 4.2.1.3.5.2 and 4.2.1.3.5.3:

- Description of the climatological, hydrological, geological, and geochemical aspects of net infiltration in the unsaturated zone, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;

- Sufficiency of the data and parameters used to justify the model abstraction;

- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.5.2 Review Methods

To review the abstraction of climate and infiltration, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of physical phenomena and couplings and the descriptions of the geological, hydrological, geochemical, paleohydrological, paleoclimatological, and climatological aspects of the abstraction of the climate and net infiltration that contribute to waste isolation. Assess the adequacy of the technical bases for these descriptions and for incorporating them in this abstraction.

Evaluate whether the description of aspects of geology, hydrology, geochemistry, physical phenomena, and couplings, that may affect climate and net infiltration, is adequate. Verify that conditions and assumptions used in this abstraction are consistent with the body of data presented in the description.

Examine assumptions, technical bases, data, and models used by the U.S. Department of Energy in this abstraction for consistency with other related U.S. Department of Energy abstractions. Evaluate whether the descriptions and technical bases provide transparent and traceable support for this abstraction.

Examine how the features, events, and processes related to climate and net infiltration have been included in the total system performance assessment abstractions.

Confirm that the U.S. Department of Energy abstractions employ adequate spatial and temporal variability of model parameters and boundary conditions to estimate net infiltration flux.

Ensure that averages of parameter estimates used in process-level models over time and space scales are appropriate for the model discretization.

Verify that paleoclimate information is evaluated over the past 500,000 years as the basis for projections of future climate change. For example, confirm that numerical climate models, if used for projection of future climate, are calibrated based on such paleoclimate data.

Verify that the U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the data used to support conceptual models, process-level models, and alternative conceptual models considered in this abstraction, and the parameters used for each of these models. Evaluate the basis for the data on physical phenomena, couplings, climatology, geology, hydrology, and geochemistry. This basis may include a combination of techniques, such as laboratory experiments, site-specific field measurements, natural analog research, process-level modeling studies, and expert elicitation.

Verify that the mathematical model estimates of present-day net infiltration are at appropriate time and space scales. Assure adequate site-specific climatic, surface, and subsurface information is used.

Verify that net infiltration is not underestimated. Assure adequate representation of the effects of fracture properties, fracture distributions, matrix properties, heterogeneities, time-varying boundary conditions, evapotranspiration, depth of soil cover, and surface-water runoff and run-on is incorporated in this abstraction.

Confirm the use of adequate sensitivity or uncertainty analyses to assess data sufficiency, and determine the possible need for additional data.

Assure adequate accepted and well-documented procedures are applied to develop and calibrate numerical models.

Verify that reasonably complete process-level conceptual and mathematical models are used in the analyses. Assure the mathematical models are consistent with conceptual models and site characteristics. Confirm that a comparison of the robustness of results from different mathematical models is provided.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation.

Review Method 3 Data Uncertainty

Verify that parameter values reasonably account for uncertainties and variabilities for the assumed ranges, probability distributions, and/or bounding assumptions. Evaluate the U.S. Department of Energy assessment of uncertainty and variability in parameters used in the model abstraction. Determine whether uncertainty in data, because of both temporal and spatial variations in conditions affecting climate and net infiltration, is incorporated into the parameter ranges. For example, evaluate the climatic and hydrostratigraphic parameters used in the abstracted model to verify that they are consistent with site characterization data, and sufficiently detailed to capture heterogeneities that may influence the distribution and rate of liquid-water flux that has moved beyond the zone of evapotranspiration.

Examine the technical bases for parameter values and ranges, probability distributions, or bounding values in conceptual models, process-level models, and alternative conceptual models considered in the abstraction. Determine whether the parameter values are derived from site-specific data, or an analysis is included to show that the assumed parameter values lead to a conservative assessment of performance. Evaluate the assessment of uncertainty and variability in these parameters.

Determine if the U.S. Department of Energy appropriately establishes possible statistical correlations between parameters. Verify that an adequate technical basis or bounding argument is provided for neglected correlations.

Confirm that performance assessments incorporate the hydrologic effects of future climate change that could alter the rates and patterns of present-day net infiltration into the unsaturated zone.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the abstraction for climate and net infiltration. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies. Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of climate and net infiltration.

Verify that the bounds of uncertainty created by the process-level models are adequately reflected in this abstraction. Where appropriate, use an alternative total system performance assessment model to verify that the U.S. Department of Energy total system performance assessment approach reflects or bounds the uncertainties in the process-level models.

Assure the conceptual model uncertainties are defined and documented, including their effects on conclusions regarding performance.

Review Method 5 Model Support

Evaluate the output from the abstraction of climate and net infiltration. Compare the results with an appropriate combination of site characterization data, process-level modeling, laboratory testing, field measurements, and natural analog data.

Assure adequate justification and technical bases exist to conservatively bound process-level models. In particular, verify that if the U.S. Department of Energy uses an abstracted model to predict water flux into the unsaturated zone, the abstracted model is shown to bound process-level model predictions of the net infiltration flux. Use detailed models of geological, hydrological, geochemical, and climatological processes to evaluate the abstraction of climate and net infiltration.

Evaluate the output of model abstractions against results produced by process-level models. Where practical, use an alternative total system performance assessment model to evaluate

selected parts of the U.S. Department of Energy abstraction, and to evaluate the effects of climate and net infiltration on repository performance.

4.2.1.3.5.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the climate and net infiltration model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- The total system performance assessment adequately incorporates, or bounds, important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the climate and net infiltration abstraction process;
- The aspects of geology, hydrology, geochemistry, physical phenomena, and couplings, that may affect climate and net infiltration, are adequately considered. Conditions and assumptions in the abstraction of climate and net infiltration are readily identified and consistent with the body of data presented in the description;
- The abstraction of climate and net infiltration uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for climate and net infiltration are consistent with the abstractions of flow paths in the unsaturated zone and flow paths in the saturated zone (Sections 4.2.1.3.6 and 4.2.1.3.8 of the Yucca Mountain Review Plan, respectively). The descriptions and technical bases provide transparent and traceable support for the abstraction of climate and net infiltration;
- Sufficient data and technical bases to assess the degree to which features, events, and processes have been included for this abstraction are provided;
- Adequate spatial and temporal variability of model parameters and boundary conditions are employed to model the different parts of the system;
- Average parameter estimates are used in process-level models over time and space scales that are appropriate for the model discretization;
- Projections of future climate change are based on evaluation of paleoclimate information over the past 500,000 years. For example, numerical climate models, if used for projection of future climate, are calibrated based on such paleoclimate data; and
- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer reviews and data qualification, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Climatological and hydrological values used in the safety case (e.g., time of onset of climate change, mean annual temperature, mean annual precipitation, mean annual net infiltration, etc.) are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;
- Estimates of present-day net infiltration using mathematical models at appropriate time and space scales are reasonably verified with site-specific climatic, surface, and subsurface information;
- The effects of fracture properties, fracture distributions, matrix properties, heterogeneities, time-varying boundary conditions, evapotranspiration, depth of soil cover, and surface-water runoff and runon are considered, such that net infiltration is not underestimated;
- Sensitivity or uncertainty analyses are performed to assess data sufficiency and determine the possible need for additional data;
- Accepted and well-documented procedures are used to construct and calibrate numerical models;
- Reasonably complete process-level conceptual and mathematical models are used in the analyses. In particular: (i) mathematical models are provided that are consistent with conceptual models and site characteristics; and (ii) the robustness of results from different mathematical models is compared; and
- Any expert elicitation conducted is in accordance with NUREG–1563 (Kotra, et al., 1996), or other acceptable approaches.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;
- The technical bases for the parameter values used in this abstraction are provided;
- Possible statistical correlations are established between parameters in this abstraction. An adequate technical basis or bounding argument is provided for neglected correlations; and
- The hydrologic effects of future climate change that may alter the rates and patterns of present-day net infiltration into the unsaturated zone are addressed. Such effects may include changes in soil depths, fracture-fill material, and types of vegetation.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction

- Alternative modeling approaches of features, events, and processes, consistent with available data and current scientific understanding, are investigated. The results and limitations are appropriately considered in the abstraction;
- The bounds of uncertainty created by the process-level models are considered in this abstraction; and
- Conceptual model uncertainties and their effects on conclusions regarding performance are defined and documented.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testing and/or natural analogs);
- Abstractions of process-level models may conservatively bound process-level predictions; and
- Comparisons are provided of output of abstracted models of climate and net infiltration with output of sensitivity studies, detailed process-level models, natural analogs, and empirical observations, as appropriate.

4.2.1.3.5.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.5.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.1.1.1.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to climate and infiltration, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment in the area of

climate and net infiltration have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a))–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual doses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.5.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.6 Flow Paths in the Unsaturated Zone

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on flow paths in the unsaturated zone, to demonstrate its safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on flow paths in the unsaturated zone to provide significant delay and/or dilution in the transport of radionuclides to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the delay in the transport of radionuclides to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that

have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.6.1 Areas of Review

This section reviews flow paths in the unsaturated zone. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (10), (15), and (19), that is relevant to the abstraction of flow paths in the unsaturated zone.

The staff will evaluate the following parts of the abstraction of flow paths in the unsaturated zone, using the review methods and acceptance criteria in Sections 4.2.1.3.6.2 and 4.2.1.3.6.3:

- Description of the hydrological, geological, and coupled thermal-hydrologic-mechanical-chemical processes of flow paths in the unsaturated zone, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.6.2 Review Methods

To review the abstraction of flow paths in the unsaturated zone, recognize that models used in the total system performance assessment may range from highly complex process-level models

to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of physical phenomena and couplings, and the descriptions of the geological, hydrological, geochemical, and thermal-hydrological-mechanical-chemical aspects

of the abstraction of flow paths in the unsaturated zone that affect waste isolation. Assess the adequacy of the technical bases for these descriptions and for incorporating them in this abstraction.

Evaluate whether the descriptions of aspects of geology, hydrology, geochemistry, physical phenomena, and couplings that may affect flow paths in the unsaturated zone are adequate. Verify that conditions and assumptions used in this abstraction are consistent with the body of data presented in the description.

Examine assumptions, technical bases, data, and models used by the U.S. Department of Energy in this abstraction for consistency with other related abstractions. Evaluate whether the descriptions and technical bases provide transparent and traceable support for this abstraction.

Determine whether the conditions and assumptions used to generate look-up tables or regression equations to describe initial and boundary conditions are consistent with other conditions and assumptions in this abstraction.

Examine how the features, events, and processes related to flow paths in the unsaturated zone have been included in the total system performance assessment abstraction.

Verify that the U.S. Department of Energy abstractions employ adequate spatial and temporal variability of model parameters and boundary conditions to estimate flow paths in the unsaturated zone, percolation flux, and seepage flux.

Verify that appropriate averages of parameter estimates are used in process-level models over time and space scales that are appropriate for the model discretization.

Confirm that potential reduction in unsaturated zone transport distances are accounted for after a climate-induced water table rise.

Verify that the U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches for peer review and data qualification.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the data used to support conceptual models, process-level models, and alternative conceptual models considered in this abstraction, and the parameters used for each of these models. Evaluate the basis for the data on physical phenomena, couplings, climatology, geology, hydrology, and geochemistry. This basis may include a combination of techniques, such as laboratory experiments, site-specific field measurements, natural analog research, process-level modeling studies, and expert elicitation.

Verify that acceptable techniques, which may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies, are used in collecting and interpreting the data regarding the geology, hydrology, and geochemistry of the unsaturated zone.

Assure that estimates of deep-percolation flux rates constitute an upper bound or reasonably represent the physical system. Verify that the flow model is calibrated using site-specific hydrologic, geologic, and geochemical data. Confirm that the mathematical model estimates of deep-percolation flux are at appropriate time and space scales.

Verify that appropriate thermal-hydrologic processes are evaluated by testing.

Confirm the use of adequate sensitivity or uncertainty analyses to assess data sufficiency, and determine the possible need for additional data.

Assure adequate accepted and well-documented procedures are applied to develop and calibrate numerical models.

Verify that reasonably complete process-level conceptual and mathematical models are used in the analyses. Assure the mathematical models are consistent with conceptual models and site characteristics. Confirm that a comparison of the robustness of results from different mathematical models is provided.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation.

Review Method 3 Data Uncertainty

Verify that parameter values reasonably account for uncertainties and variabilities for the assumed ranges, probability distributions, and/or bounding assumptions. Evaluate the U.S. Department of Energy assessment of uncertainty and variability in parameters used in the model abstraction. Determine whether uncertainty in data, from both temporal and spatial variations in conditions affecting flow paths in the unsaturated zone, is incorporated into the parameter ranges.

Examine the technical bases for parameter values and ranges, probability distributions, or bounding values in conceptual models, process-level models, and alternative conceptual models, considered in the total system performance assessment abstraction. Determine whether the parameter values are derived from site-specific data, or an analysis is included to show that the assumed parameter values lead to a reasonable assessment of performance. Evaluate the assessment of uncertainty and variability in these parameters.

Determine if the U.S. Department of Energy appropriately established possible statistical correlations between parameters. Verify that an adequate technical basis or bounding argument is provided for neglected correlations.

Examine the initial conditions, boundary conditions, and computational domain used in sensitivity analyses and/or similar analyses for consistency with available data.

Verify that coupled thermal-hydrologic-mechanical-chemical processes are properly evaluated. Ensure that uncertainties in the characteristics of the natural system and engineered materials are considered.

Confirm that parameter values are consistent with the initial and boundary conditions and the assumptions of the conceptual models for the Yucca Mountain site.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the abstraction for flow paths in the unsaturated zone. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies. Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of flow paths in the unsaturated zone.

Verify that the bounds of uncertainty created by the process-level models are adequately reflected in this abstraction. Where appropriate, use an alternative total system performance assessment model to verify that the U.S. Department of Energy total system performance assessment approach reflects or bounds the uncertainties in the process-level models.

Assure the conceptual model uncertainties are defined and documented, including their effects on conclusions regarding performance.

Review Method 5 Model Support

Evaluate the output from the abstraction of flow paths in the unsaturated zone. Compare the results with an appropriate combination of site characterization data, process-level modeling, laboratory testing, field measurements, and natural analog data.

Assure adequate justification and technical basis exist to conservatively bound process-level models. Use detailed models of geological, hydrological, geochemical, and thermal-hydrologic-mechanical-chemical processes, to evaluate the total system performance assessment abstractions of flow paths in the unsaturated zone.

Evaluate the output of model abstractions against results produced by process-level models. Where practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction, and to evaluate the effects of flow paths in the unsaturated zone on repository performance.

4.2.1.3.6.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)()–(c) and (e)–(g), relating to the flow paths in the unsaturated zone model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- The total system performance assessment adequately incorporates, or bounds, important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the flow paths in the unsaturated zone abstraction process. Couplings include thermal-hydrologic-mechanical-chemical effects, as appropriate;

- The aspects of geology, hydrology, geochemistry, physical phenomena, and couplings that may affect flow paths in the unsaturated zone are adequately considered. Conditions and assumptions in the abstraction of flow paths in the unsaturated zone are readily identified and consistent with the body of data presented in the description;

- The abstraction of flow paths in the unsaturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for flow paths in the unsaturated zone are consistent with the abstractions of quantity and chemistry of water contacting waste packages and waste forms, climate and infiltration, and flow paths in the saturated zone (Sections 4.2.1.3.3, 4.2.1.3.5, and 4.2.1.3.8 of the Yucca Mountain Review Plan, respectively). The descriptions and technical bases are transparent and traceable to site and design data;

- The bases and justification for modeling assumptions and approximations of radionuclide transport in the unsaturated zone are consistent with those used in model abstractions for flow paths in the unsaturated zone and thermal-hydrologic-mechanical-chemical effects;

- Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided;

- Adequate spatial and temporal variability of model parameters and boundary conditions are employed in process-level models to estimate flow paths in the unsaturated zone, percolation flux, and seepage flux;

- Average parameter estimates used in process-level models are representative of the temporal and spatial discretizations considered in the model;

- Reduction in unsaturated zone transport distances, after a climate-induced water table rise, is considered; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer review and data qualification, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Hydrological and thermal-hydrological-mechanical-chemical values used in the safety case are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;

- The data on the geology, hydrology, and geochemistry of the unsaturated zone, are collected using acceptable techniques;

- Estimates of deep-percolation flux rates constitute an upper bound, or are based on a technically defensible unsaturated zone flow model that reasonably represents the physical system. The flow model is calibrated, using site-specific hydrologic, geologic, and geochemical data. Deep-percolation flux is estimated, using the appropriate spatial and temporal variability of model parameters, and boundary conditions that consider climate-induced change in soil depths and vegetation;

- Appropriate thermal-hydrologic tests are designed and conducted, so that critical thermal-hydrologic processes can be observed, and values for relevant parameters estimated;

- Sensitivity or uncertainty analyses are performed to assess data sufficiency, and determine the possible need for additional data;

- Accepted and well-documented procedures are used to construct and calibrate numerical models;

- Reasonably complete process-level conceptual and mathematical models are used in the analyses. In particular: (i) mathematical models are provided that are consistent with conceptual models and site characteristics; and (ii) the robustness of results from different mathematical models is compared; and

- Any expert elicitation conducted is in accordance with NUREG–1563 (Kotra, et al., 1996), or other acceptable approaches.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;

- The technical bases for the parameter values used in this abstraction are provided;

- Possible statistical correlations are established between parameters in this abstraction. An adequate technical basis or bounding argument is provided for neglected correlations;

- The initial conditions, boundary conditions, and computational domain used in sensitivity analyses and/or similar analyses are consistent with available data. Parameter values are consistent with the initial and boundary conditions and the assumptions of the conceptual models for the Yucca Mountain site;

- Coupled processes are adequately represented; and

- Uncertainties in the characteristics of the natural system and engineered materials are considered.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes, consistent with available data and current scientific understanding, are investigated. The results and limitations are appropriately considered in the abstraction;
- The bounds of uncertainty created by the process-level models are considered in this abstraction; and
- Conceptual model uncertainties, and their effects on conclusions regarding performance, are defined and documented.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testing and/or natural analogs);
- Abstractions of process-level models conservatively bound process-level predictions; and
- Comparisons are provided of output of abstracted model of flow paths in the unsaturated zone with outputs of sensitivity studies, detailed process-level models, natural analogs, and empirical observations, as appropriate.

4.2.1.3.6.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.6.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to flow paths in the unsaturated zone, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment

in the area of flow paths in the unsaturated zone have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.6.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.7 Radionuclide Transport in the Unsaturated Zone

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on radionuclide transport through the unsaturated zone, to demonstrate its safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on the unsaturated zone to provide significant delay in the transport of radionuclides and/or dilution of concentration to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the delay, or a minor impact on the dose to the reasonably maximally exposed individual, then conduct a simplified review, focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The

demonstration of compliance with the performance objectives is evaluated using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.7.1 Areas of Review

This section reviews radionuclide transport in the unsaturated zone. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (10), (15), and (19), that is relevant to the abstraction of radionuclide transport in the unsaturated zone.

The staff will evaluate the following parts of the abstraction of radionuclide transport in the unsaturated zone, using the review methods and acceptance criteria in Sections 4.2.1.3.7.2 and 4.2.1.3.7.3

- Description of the geological, hydrological, and geochemical aspects of radionuclide transport in the unsaturated zone, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.7.2 Review Methods

To review the abstraction of radionuclide transport in the unsaturated zone, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings, and the description of the geological, hydrological, and geochemical aspects of the unsaturated zone

included in the abstraction of radionuclide transport in the unsaturated zone, that affect waste isolation. Assess the adequacy of the technical bases for these descriptions, and for incorporating them in the abstraction of radionuclide transport in the unsaturated zone.

Evaluate whether the description of aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect radionuclide transport in the unsaturated zone, is adequate. Verify that conditions and assumptions used in the total system performance assessment abstraction of radionuclide transport in the unsaturated zone are consistent with the data presented in the description.

Examine assumptions, technical bases, data, and models used by the U.S. Department of Energy in the abstraction of radionuclide transport in the unsaturated zone for consistency with other related U.S. Department of Energy abstractions. Evaluate whether the descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the unsaturated zone.

Confirm that the U.S. Department of Energy has propagated boundary and initial conditions, used in the abstraction of radionuclide transport in the unsaturated zone throughout its abstraction approaches.

Examine how the features, events, and processes related to radionuclide transport in the unsaturated zone, have been included in the total system performance assessment abstraction.

Verify that the U.S. Department of Energy follows guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or makes an acceptable case for using alternative approaches for peer review and data qualification.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, hydrological, and geochemical data used to support parameters, used in conceptual models, process-level models, and alternative conceptual models, considered in the abstraction of radionuclide transport in the unsaturated zone. Assess the sufficiency, transparency, and traceability of the data used to support the technical bases for features, events, and processes that have been included in the abstraction of radionuclide transport in the unsaturated zone.

Verify whether sufficient data have been collected on the characteristics of the geology, hydrology, and geochemistry of the natural system to establish initial and boundary conditions for the abstraction of radionuclide transport in the unsaturated zone.

Evaluate and confirm that data used to support the U.S. Department of Energy abstraction of radionuclide transport in the unsaturated zone are based on appropriate techniques, and are

adequate for the accompanying sensitivity/uncertainty analyses. Evaluate the need for additional data based on the sensitivity analyses.

Review Method 3 Data Uncertainty

Evaluate the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions used in conceptual models, process models, and alternative conceptual models considered in the abstraction of radionuclide transport in the unsaturated zone. Evaluate the assessment of uncertainty and variability in these parameters, and verify that the technical bases reasonably account for uncertainties and variabilities in the data.

Determine whether the U.S. Department of Energy has used flow and transport parameters that are based on techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies, conducted under conditions relevant to the unsaturated zone at Yucca Mountain. Examine the results of the U.S. Department of Energy field transport tests, and confirm that the U.S. Department of Energy has provided adequate models.

If criticality in the unsaturated zone is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor. Evaluate the consequences calculated by the U.S. Department of Energy for criticality in the unsaturated zone.

Assess how uncertainty is represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of radionuclide transport in the unsaturated zone.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models, used in developing the abstraction for radionuclide transport in the unsaturated zone. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies, and evaluate their consistency.

Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of radionuclide transport in the unsaturated zone. Examine the effects of the alternative conceptual model(s) on repository performance, and evaluate how model uncertainties are defined, documented, and assessed.

Examine the mathematical models included in the analyses of radionuclide transport in the unsaturated zone. Examine and evaluate the bases for excluding alternative conceptual models, and the limitations and uncertainties of the chosen model.

Review Method 5 Model Support

Evaluate the output from the abstraction of radionuclide transport in the unsaturated zone, and compare the results with an appropriate combination of site characterization data, process

modeling, laboratory testing, field measurements, and natural analog research. Evaluate the sensitivity analyses used to support the abstraction of radionuclide transport in the unsaturated zone in the total system performance assessment.

Use detailed models of geochemical, hydrological, and geological processes to evaluate the total system performance assessment abstractions of radionuclide transport in the unsaturated zone. If practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of radionuclide transport in the unsaturated zone, and evaluate the effects on repository performance. Compare results of the U.S. Department of Energy abstraction to approximations shown to be appropriate for closely analogous natural systems or experimental systems.

Examine the procedures used by the U.S. Department of Energy to develop and test its mathematical and numerical models.

As appropriate, use an alternative total system performance assessment model to evaluate the U.S. Department of Energy sensitivity or bounding analyses, and confirm that the U.S. Department of Energy has used ranges consistent with available site characterization data, field and laboratory tests, and natural analog research.

4.2.1.3.7.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)()–(c) and (e)–(g) , relating to the radionuclide transport in the unsaturated zone model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the radionuclide transport in the unsaturated zone abstraction process;

- The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect radionuclide transport in the unsaturated zone, is adequate. For example, the description includes changes in transport properties in the unsaturated zone, from water-rock interaction. Conditions and assumptions in the total system performance assessment abstraction of radionuclide transport in the unsaturated zone are readily identified, and consistent with the body of data presented in the description;

- The abstraction of radionuclide transport in the unsaturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, assumptions used for radionuclide transport in the unsaturated zone are consistent with the abstractions of radionuclide release rates and solubility limits and flow paths in the unsaturated zone

(Sections 4.2.1.3.4 and 4.2.1.3.6 of the Yucca Mountain Review Plan, respectively). The descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the unsaturated zone;

- Boundary and initial conditions used in the abstraction of radionuclide transport in the unsaturated zone are propagated throughout its abstraction approaches. For example, the conditions and assumptions used to generate transport parameter values are consistent with other geological, hydrological, and geochemical conditions in the total system performance assessment abstraction of the unsaturated zone;

- Sufficient data and technical bases for the inclusion of features, events, and processes, related to radionuclide transport in the unsaturated zone in the total system performance assessment abstraction, are provided; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches, is followed for peer review and data qualification.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Geological, hydrological, and geochemical values, used in the safety case, are adequately justified (e.g., flow-path length, sorption coefficients, retardation factors, colloid concentrations, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;

- Sufficient data have been collected on the characteristics of the natural system to establish initial and boundary conditions for the total system performance assessment abstraction of radionuclide transport in the unsaturated zone; and

- Data on the geology, hydrology, and geochemistry of the unsaturated zone, including the influence of structural features, fracture distributions, fracture properties, and stratigraphy, used in the total system performance assessment abstraction are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses, used to support the U.S. Department of Energy total system performance assessment abstraction, are adequate to determine the possible need for additional data.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;

- For those radionuclides where the total system performance assessment abstraction indicates that transport in fractures and matrix in the unsaturated zone is important to performance: (i) estimated flow and transport parameters are appropriate and valid, based on techniques that may include laboratory experiments, field measurements,

natural analog research, and process-level modeling studies, conducted under conditions relevant to the unsaturated zone at Yucca Mountain; and (ii) models are demonstrated to adequately reproduce field transport test results. For example, if a sorption coefficient approach is used, the assumptions implicit in that approach are verified;

- If criticality in the unsaturated zone far field is included in the total system performance assessment, an appropriate range of input parameters for calculating the effective neutron multiplication factor is used. The effects on performance of criticality in the unsaturated zone are adequately evaluated;

- Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of radionuclide transport in the unsaturated zone. This may be done either through sensitivity analyses or use of conservative limits.

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed; and

- Appropriate alternative modeling approaches are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations, using tests and analyses that are sensitive to the processes modeled. For example, for radionuclide transport through fractures, the U.S. Department of Energy adequately considers alternative modeling approaches, to develop its understanding of fracture distributions and ranges of fracture flow and transport properties in the unsaturated zone.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Outputs of radionuclide transport in the unsaturated zone abstractions reasonably produce or bound the results of corresponding process-level models, empirical

observations, or both. The U.S. Department of Energy abstracted models for radionuclide transport in the unsaturated zone are based on the same hydrological, geological, and geochemical assumptions and approximations, shown to be appropriate for closely analogous natural systems or experimental systems;

- Well-documented procedures that have been accepted by the scientific community to construct and test the mathematical and numerical models are used to simulate radionuclide transport through the unsaturated zone; and

- Sensitivity analyses or bounding analyses are provided, to support the total system performance assessment abstraction of radionuclide transport in the unsaturated zone, that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.

4.2.1.3.7.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.7.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to radionuclide transport in the unsaturated zone, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment in the area of radionuclide transport in the unsaturated zone have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.7.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.8 Flow Paths in the Saturated Zone

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on flow paths in the saturated zone to demonstrate its safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on saturated zone flow to provide significant delay or dilution in the transport of radionuclides to the reasonably maximally exposed individual, then perform a review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the dose to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated, using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.8.1 Areas of Review

This section reviews flow paths in the saturated zone. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15), and (19), that is relevant to the abstraction of flow paths in the saturated zone.

The staff will evaluate the following parts of the abstraction of flow paths in the saturated zone, using the review methods and acceptance criteria in Sections 4.2.1.3.8.2 and 4.2.1.3.8.3:

- Description of the geological, hydrological, and geochemical aspects of flow paths in the saturated zone, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;

- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.8.2 Review Methods

To review the abstraction of flow paths in the saturated zone, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings, and the description of the geological, hydrological, and geochemical aspects of the saturated zone, included in the abstraction of flow paths, in the saturated zone, that affect waste isolation. Assess the adequacy of the technical bases for these descriptions, and for incorporating them in the abstraction of flow paths in the saturated zone.

Evaluate whether the description of aspects of geology, hydrology, geochemistry, design features, physical phenomena, and couplings, that may affect flow paths in the saturated zone, is adequate. Verify that conditions and assumptions used in the abstraction of flow paths in the saturated zone are consistent with the body of data presented in the description.

Examine assumptions, technical bases, data, and models used by the U.S. Department of Energy in the abstraction of flow paths in the saturated zone for consistency with other related U.S. Department of Energy abstractions. Evaluate whether the descriptions and technical bases provide transparent and traceable support for the abstraction of flow paths in the saturated zone.

Confirm that the U.S. Department of Energy has propagated boundary and initial conditions, used in the abstraction of flow paths in the saturated zone, throughout its abstraction approaches.

Examine how the features, events, and processes, related to flow paths in the saturated zone have been included in the total system performance assessment abstraction.

Ensure that the U.S. Department of Energy delineates the flow paths in the saturated zone, considering natural site conditions.

Verify that the U.S. Department of Energy evaluates long-term climate change, based on known patterns of climatic cycles, during the Quaternary period, particularly the last 500,000 years, and other paleoclimate data.

Confirm that the U.S. Department of Energy considers potential geothermal and seismic effects on the ambient saturated zone flow system.

Ensure that the U.S. Department of Energy considers the impact of the expected water table rise on potentiometric heads and flow directions, and consequently on repository performance.

Verify that the U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, hydrological, geochemical, and climatological data used to support parameters used in conceptual models, process-level models, and alternative conceptual models considered in the total system performance assessment abstraction of flow paths in the saturated zone. Evaluate the basis for the data on physical phenomena, couplings, climatology, geology, hydrology, and geochemistry used in the total system performance assessment abstraction of flow paths in the saturated zone. This basis may include a combination of techniques, such as laboratory experiments, site-specific field measurements, natural analog research, process-level modeling studies, and expert elicitation.

Verify that sufficient data have been collected on the characteristics of the geology, hydrology, and geochemistry of the natural system, to establish initial and boundary conditions for the total system performance assessment abstraction of flow paths in the saturated zone.

Evaluate and confirm that data used to support the U.S. Department of Energy total system performance assessment abstraction of flow paths in the saturated zone are based on appropriate techniques, and are adequate for the accompanying sensitivity/uncertainty analyses. Evaluate the need for additional data, based on sensitivity analyses.

Ensure that the U.S. Department of Energy provides sufficient information to substantiate that the proposed mathematical ground-water modeling approach, and proposed model(s) are applicable to site conditions.

Review Method 3 Data Uncertainty

Evaluate the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions used in conceptual models, process-level models, and alternative conceptual models, considered in the total system performance assessment abstraction of flow paths in the saturated zone. Evaluate the assessment of uncertainty and variability in these

parameters, and verify that the technical bases reasonably account for uncertainties and variabilities in the data.

Confirm that model abstractions incorporate uncertainty in hydrologic effects of climate change, based on a reasonably complete search of paleoclimate data.

Assess how uncertainty is represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the total system performance assessment abstraction of flow paths in the saturated zone.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the abstraction for flow paths in the saturated zone. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies, and evaluate their consistency. Confirm that the U.S. Department of Energy has adequately addressed comments from external reviews of the model abstraction.

Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of flow paths in the saturated zone. Examine the effects of the alternative conceptual model(s) on repository performance, and evaluate how model uncertainties are defined, documented, and assessed.

Examine the mathematical models included in the analyses of flow paths in the saturated zone. Also, examine and evaluate the bases for excluding alternative conceptual models, and the limitations and uncertainties of the chosen model.

Review Method 5 Model Support

Evaluate the output from the abstraction of flow paths in the saturated zone, and compare the results with an appropriate combination of site characterization data, process-level modeling, laboratory testing, field measurements, and natural analog research.

Use detailed models of geological, hydrological, and geochemical processes to evaluate the total system performance assessment abstractions of flow paths in the saturated zone. If practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of flow paths in the saturated zone, and evaluate the effects on repository performance. Compare results of the U.S. Department of Energy abstraction to approximations shown to be appropriate for closely analogous natural systems or experimental systems.

Examine the procedures used by the U.S. Department of Energy to develop and test its mathematical and numerical models.

As appropriate, use an alternative total system performance assessment model to evaluate the U.S. Department of Energy sensitivity or bounding analyses, and confirm that the U.S. Department of Energy has used ranges consistent with available site characterization data, field and laboratory tests, and natural analog research.

4.2.1.3.8.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the flow paths in the saturated zone model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions, throughout the flow paths in the saturated zone abstraction process;

- The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect flow paths in the saturated zone, is adequate. Conditions and assumptions in the abstraction of flow paths in the saturated zone are readily identified, and consistent with the body of data presented in the description;

- The abstraction of flow paths in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for flow paths in the saturated zone are consistent with the total system performance assessment abstraction of representative volume (Section 4.2.1.3.12 of the Yucca Mountain Review Plan). The descriptions and technical bases provide transparent and traceable support for the abstraction of flow paths in the saturated zone;

- Boundary and initial conditions used in the total system performance assessment abstraction of flow paths in the saturated zone are propagated throughout its abstraction approaches. For example, abstractions are based on initial and boundary conditions consistent with site-scale modeling and regional models of the Death Valley ground-water flow system;

- Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided;

- Flow paths in the saturated zone are adequately delineated, considering natural site conditions;

- Long-term climate change, based on known patterns of climatic cycles during the Quaternary period, particularly the last 500,000 years, and other paleoclimate data, are adequately evaluated;

- Potential geothermal and seismic effects on the ambient saturated zone flow system are adequately described and accounted for;

- The impact of the expected water table rise on potentiometric heads and flow directions, and consequently on repository performance, is adequately considered; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Geological, hydrological, and geochemical values used in the safety case to evaluate flow paths in the saturated zone are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;

- Sufficient data have been collected on the natural system to establish initial and boundary conditions for the abstraction of flow paths in the saturated zone;

- Data on the geology, hydrology, and geochemistry of the saturated zone used in the total system performance assessment abstraction are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses, used to support the U.S. Department of Energy total system performance assessment abstraction, are adequate to determine the possible need for additional data; and

- Sufficient information is provided to substantiate that the proposed mathematical ground-water modeling approach and proposed model(s) are calibrated and applicable to site conditions.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities. For example, the U.S. Department of Energy provides sufficient bases for selection of hydrologic parameter values and statistical distributions;

- Uncertainty is appropriately incorporated in model abstractions of hydrologic effects of climate change, based on a reasonably complete search of paleoclimate data;

- Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of flow paths in the saturated zone. This may be done either through sensitivity analyses or use of conservative limits. For example, sensitivity analyses and/or similar analyses are sufficient to identify saturated zone flow parameters that are expected to significantly affect the abstraction model outcome; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their uses.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed. For example, uncertainty in data interpretations is considered by analyzing reasonable conceptual flow models that are supported by site data, or by demonstrating through sensitivity studies that the uncertainties have little impact on repository performance; and

- Appropriate alternative modeling approaches are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations, using tests and analyses that are sensitive to the processes modeled.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Outputs of flow paths in the saturated zone abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both;

- Well-documented procedures that have been accepted by the scientific community to construct and test the mathematical and numerical models are used to simulate flow paths in the saturated zone; and

- Sensitivity analyses or bounding analyses are provided to support the abstraction of flow paths in the saturated zone, that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.

4.2.1.3.8.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.8.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to flow paths in the saturated zone, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment in the area of flow paths in the saturated zone have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.8.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.9 Radionuclide Transport in the Saturated Zone

To review this model abstraction, the staff will evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on radionuclide transport through the saturated zone, to demonstrate its safety case. Review this model abstraction considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on the saturated zone to provide significant delay in the transport of radionuclides and/or dilution of concentration to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the dose to the reasonably maximally exposed individual, then conduct a

simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated, using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.9.1 Areas of Review

This section reviews radionuclide transport in the saturated zone. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15), and (19), that is relevant to the abstraction of radionuclide transport in the saturated zone.

The staff will evaluate the following parts of the abstraction of radionuclide transport in the saturated zone, using the review methods and acceptance criteria in Sections 4.2.1.3.9.2 and 4.2.1.3.9.3:

- Description of the geological, hydrological, and geochemical aspects of radionuclide transport in the saturated zone, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output with process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.9.2 Review Methods

To review the abstraction of radionuclide transport in the saturated zone, recognize that models used in the total system performance assessments may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings, and the description of the geological, hydrological, and geochemical aspects of the saturated zone included in the abstraction of radionuclide transport in the saturated zone that contribute to waste isolation. Assess the adequacy of the technical bases for these descriptions, and for incorporating them in the abstraction of radionuclide transport in the saturated zone.

Evaluate whether the description of aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect radionuclide transport in the saturated zone, is adequate. Verify that conditions and assumptions used in the abstraction of radionuclide transport in the saturated zone are consistent with the body of data presented in the description.

Examine assumptions, technical bases, data, and models used by the U.S. Department of Energy in the total system performance assessment abstraction of radionuclide transport in the saturated zone for consistency with other related U.S. Department of Energy abstractions. Evaluate whether the descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the saturated zone.

Confirm that the U.S. Department of Energy has propagated boundary and initial conditions, used in the abstraction of radionuclide transport in the saturated zone, throughout its abstraction approaches.

Examine how the features, events, and processes, related to radionuclide transport in the saturated zone, have been included in the total system performance assessment abstraction.

Verify that the U.S. Department of Energy follows guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or makes an acceptable case for using alterative approaches to peer review and data qualification.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, hydrological, and geochemical data used to support parameters used in conceptual models, process-level models, and alternative conceptual models, considered in the abstraction of radionuclide transport in the saturated zone. Assess the sufficiency, transparency, and traceability of the data, used to support the technical bases for features, events, and processes, that have been included in the abstraction of radionuclide transport in the saturated zone.

Verify whether sufficient data have been collected on the characteristics of the geology, hydrology, and geochemistry of the natural system to establish initial and boundary conditions for the abstraction of radionuclide transport in the saturated zone.

Evaluate and confirm that data used to support the U.S. Department of Energy abstraction of radionuclide transport in the saturated zone are based on appropriate techniques, and are adequate for the accompanying sensitivity/uncertainty analyses. Evaluate the need for additional data based on the sensitivity analyses.

Review Method 3 Data Uncertainty

Evaluate the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions used in conceptual models, process models, and alternative conceptual models considered in the abstraction of radionuclide transport in the saturated zone. Evaluate the assessment of uncertainty and variability in these parameters, and verify that the technical bases reasonably account for uncertainties and variabilities in the data.

Determine whether the U.S. Department of Energy has used flow and transport parameters that are based on techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies, conducted under conditions relevant to the saturated zone at Yucca Mountain. Examine the results of the U.S. Department of Energy field transport tests, and confirm that the U.S. Department of Energy has provided adequate models.

If criticality in the saturated zone is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor. Evaluate the consequences calculated by the U.S. Department of Energy for criticality in the saturated zone.

Assess how uncertainty is represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the total system performance assessment abstraction of radionuclide transport in the saturated zone.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the U.S. Department of Energy alternative conceptual models used in developing the total system performance assessment abstraction for radionuclide transport in the saturated zone. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies, and evaluate their consistency.

Where appropriate, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of radionuclide transport in the saturated zone. Examine the effects of the alternative conceptual model(s) on repository performance, and evaluate how model uncertainties are defined, documented, and assessed.

Examine the mathematical models included in the analyses of radionuclide transport in the saturated zone. Examine and evaluate the bases for excluding alternative conceptual models, and the limitations and uncertainties of the chosen model.

Review Method 5 Model Support

Evaluate the output from the abstraction of radionuclide transport in the saturated zone, and compare the results with an appropriate combination of site characterization data, process modeling, laboratory testing, field measurements, and natural analog research. Evaluate the sensitivity analyses used to support the abstraction of radionuclide transport in the saturated zone in the total system performance assessment.

Use detailed models of geochemical, hydrological, and geological processes to evaluate the abstraction of radionuclide transport in the saturated zone. If practical, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy abstraction of radionuclide transport in the saturated zone, and evaluate the effects on repository performance. Compare results of the U.S. Department of Energy abstraction with approximations shown to be appropriate for closely analogous natural systems or experimental systems.

Examine the procedures used by the U.S. Department of Energy to develop and test its mathematical and numerical models.

As appropriate, use an alternative total system performance assessment model to evaluate the U.S. Department of Energy sensitivity or bounding analyses, and confirm that the U.S. Department of Energy has used ranges consistent with available site characterization data, field and laboratory tests, and natural analog research.

4.2.1.3.9.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the radionuclide transport in the saturated zone model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the radionuclide transport in the saturated zone abstraction process;

- The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect radionuclide transport in the saturated zone, is adequate. For example, the description includes changes in transport properties in the saturated zone, from water-rock interaction. Conditions and assumptions in the abstraction of radionuclide transport in the saturated zone are readily identified, and consistent with the body of data presented in the description;

- The abstraction of radionuclide transport in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, assumptions used for radionuclide transport in the saturated zone are consistent with the total system performance assessment abstractions of radionuclide release rates and solubility limits, and flow paths in the saturated zone (Sections 4.2.1.3.4 and 4.2.1.3.8 of the Yucca Mountain Review Plan, respectively). The descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the saturated zone;

- Boundary and initial conditions used in the abstraction of radionuclide transport in the saturated zone are propagated throughout its abstraction approaches. For example, the conditions and assumptions used to generate transport parameter values are consistent with other geological, hydrological, and geochemical conditions in the total system performance assessment abstraction of the saturated zone;

- Sufficient data and technical bases for the inclusion of features, events, and processes related to radionuclide transport in the saturated zone in the total system performance assessment abstraction are provided; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Geological, hydrological, and geochemical values used in the safety case are adequately justified (e.g., flow path lengths, sorption coefficients, retardation factors, colloid concentrations, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;

- Sufficient data have been collected on the characteristics of the natural system to establish initial and boundary conditions for the total system performance assessment abstraction of radionuclide transport in the saturated zone; and

- Data on the geology, hydrology, and geochemistry of the saturated zone, including the influence of structural features, fracture distributions, fracture properties, and stratigraphy, used in the total system performance assessment abstraction, are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the U.S. Department of Energy total system performance assessment abstraction are adequate to determine the possible need for additional data.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;

- For those radionuclides where the total system performance assessment abstraction indicates that transport in fractures and matrix in the saturated zone is important to performance: (i) estimated flow and transport parameters are appropriate and valid, based on techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies conducted under conditions relevant to the saturated zone at Yucca Mountain; and (ii) models are demonstrated to adequately predict field transport test results. For example, if a sorption coefficient approach is used, the assumptions implicit in that approach are validated;

- If criticality in the saturated zone is included in the total system performance assessment, an appropriate range of input parameters for calculating the effective neutron multiplication factor is used. The effects on performance of criticality in the saturated zone are adequately evaluated;

- Parameter values for processes, such as matrix diffusion, dispersion, and ground-water mixing, are based on reasonable assumptions about climate, aquifer properties, and ground-water volumetric fluxes (Section 4.2.1.3.8 of the Yucca Mountain Review Plan);

- Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the abstraction of radionuclide transport in the saturated zone. This may be done either through sensitivity analyses or use of conservative limits; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of other sources, such as expert elicitation conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;

- Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed; and

- Appropriate alternative modeling approaches are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations

using tests and analyses that are sensitive to the processes modeled. For example, for radionuclide transport through fractures, the U.S. Department of Energy adequately considers alternative modeling approaches to develop its understanding of fracture distributions and ranges of fracture flow and transport properties in the saturated zone.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);

- Outputs of radionuclide transport in the saturated zone abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both. The U.S. Department of Energy-abstracted models for radionuclide transport in the saturated zone are based on the same hydrological, geological, and geochemical assumptions and approximations shown to be appropriate for closely analogous natural systems or experimental systems;

- Well-documented procedures that have been accepted by the scientific community to construct and test the mathematical and numerical models are used to simulate radionuclide transport through the saturated zone; and

- Sensitivity analyses or bounding analyses are provided, to support the total system performance assessment abstraction of radionuclide transport in the saturated zone, that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.

4.2.1.3.9.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.9.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to radionuclide transport in the saturated zone ,and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment in the area of radionuclide transport in the saturated zone have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided, for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.9.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.10 Volcanic Disruption of Waste Packages

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on volcanic disruption of waste packages to demonstrate its safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" (Section 4.2.1.1). For example, if the U.S. Department of Energy relies on waste package integrity to have a significant effect on dose to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on dose to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated, using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.10.1 Areas of Review

This section reviews volcanic disruption of waste packages. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15) and (19), that is relevant to the abstraction of volcanic disruption of waste packages.

The staff will evaluate the following parts of the abstraction of volcanic disruption of waste packages, using the review methods and acceptance criteria in Sections 4.2.1.3.10.2 and 4.2.1.3.10.3:

- Description of the geological, hydrological, geochemical and design aspects of volcanic disruption of waste packages, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output with process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.10.2 Review Methods

To review the abstraction of volcanic disruption of waste packages, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings, and the description of the geology, geophysics, and geochemistry included in the abstraction of volcanic disruption of waste packages. Assess the adequacy and consistency of the technical bases for these descriptions, and for incorporating them into the total system performance assessment abstraction for volcanic disruption of waste packages. Confirm that models and assumptions used to evaluate volcanic disruption of waste packages are consistent with models and assumptions used elsewhere in the license application.

Determine that models used to assess volcanic disruption of waste packages are consistent with physical processes generally interpreted from igneous features in the Yucca Mountain region. Verify that models of active igneous processes are consistent with processes generally observed at active igneous features.

Evaluate the technical bases used to assess the effects of interactions between engineered repository systems and igneous systems.

Verify that U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches to peer review and data qualification.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, geophysical, and geochemical data used to support parameters used in conceptual models, process-level models, and alternative conceptual models considered in the total system performance assessment abstraction of volcanic disruption of waste packages.

Determine whether the technical bases for these data are adequately justified, and that data used to model processes affecting volcanic disruption of waste packages are derived, to the extent possible, from adequately documented techniques. Such techniques may include site-specific field measurements, natural analog investigations, and laboratory experiments.

Determine that sufficient data are available to integrate features, events, and processes relevant to volcanic disruption of waste packages into process-level models. Determine that appropriate interrelationships and correlations between relevant features, events, and processes are adequately considered in resulting model abstractions.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 3 Data Uncertainty

Examine the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions used in conceptual models, process-level models, and alternative conceptual models, considered in the total system performance assessment abstraction of volcanic disruption of waste packages. Evaluate the assessment of uncertainty and variability in these parameters, and verify that the technical bases reasonably account for uncertainties and variabilities in the data.

Examine the technical bases used to quantify uncertainty in parameter values observed in site data and the available literature (i.e., data precision), and the uncertainty in abstracting parameter values to process-level models (i.e., data accuracy), to ensure that adequate measures of uncertainty and variability have been considered.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the alternative conceptual models used in developing the total system performance assessment abstraction for volcanic disruption of waste packages. Examine the model parameters, considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies, and evaluate their consistency.

Determine that uncertainties in abstracted models are adequately defined and documented. Verify that effects of these uncertainties are assessed in the total system performance assessment. Where appropriate, use an alternative total system performance assessment model to evaluate the effects of alternative models on repository performance.

Review Method 5 Model Support

Evaluate the output from the abstraction of volcanic disruption of waste packages, and compare the results with an appropriate combination of site characterization data, detailed process-level modeling, laboratory testing, field measurements, and natural analog research.

Determine that inconsistencies between abstracted models and comparative data are explained and quantified. Confirm that the resulting uncertainty is accounted for in the model results.

4.2.1.3.10.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the volcanic disruption of waste package model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the volcanic disruption of the waste package abstraction process;
- Models used to assess volcanic disruption of waste packages are consistent with physical processes generally interpreted from igneous features in the Yucca Mountain region and/or observed at active igneous systems;
- Models account for changes in igneous processes, that may occur from interactions with engineered repository systems; and
- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Parameter values used in the safety case to evaluate volcanic disruption of waste packages are sufficient and adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;
- Data used to model processes affecting volcanic disruption of waste packages are derived from appropriate techniques. These techniques may include site-specific field measurements, natural analog investigations, and laboratory experiments;
- Sufficient data are available to integrate features, events, and processes, relevant to volcanic disruption of waste packages into process-level models, including determination of appropriate interrelationships and parameter correlations; and
- Where sufficient data do not exist, the definition of parameter values and associated conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;
- Parameter uncertainty accounts quantitatively for the uncertainty in parameter values observed in site data and the available literature (i.e., data precision), and the uncertainty in abstracting parameter values to process-level models (i.e., data accuracy); and
- Where sufficient data do not exist, the definition of parameter values and associated uncertainty is based on appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches to volcanic disruption of the waste package are considered and are consistent with available data and current scientific understandings, and the results and limitations are appropriately considered in the abstraction; and
- Uncertainties in abstracted models are adequately defined and documented, and effects of these uncertainties are assessed in the total system performance assessment.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Models implemented in the volcanic disruption of waste packages abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs); and

- Inconsistencies between abstracted models and comparative data are documented, explained, and quantified. The resulting uncertainty is accounted for in the model results.

4.2.1.3.10.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.10.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to volcanic disruption of waste packages, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 in this section. Technical requirements for conducting a performance assessment in the area of volcanic disruption of waste packages have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that, in regard to volcanic disruption of the waste package:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.10.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.11 Airborne Transport of Radionuclides

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which the U.S. Department of Energy relies on airborne transport of radionuclides, to demonstrate its safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy relies on waste package integrity to provide significant delay or dilution in the transport of radionuclides to the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the delay of radionuclides to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the performance objectives is evaluated, using Section 4.2.1.4 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.11.1 Areas of Review

This section reviews airborne transport of radionuclides. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15), and (19), that is relevant to the abstraction of airborne transport of radionuclides.

The staff will evaluate the following parts of the abstraction of airborne transport of radionuclides, using the review methods and acceptance criteria in Sections 4.2.1.3.11.2 and 4.2.1.3.11.3:

- Description of the geological, hydrological, geochemical, and meteorological aspects of airborne transport of radionuclides, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;

- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;

- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;

- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;

- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and

- Use of expert elicitation.

4.2.1.3.11.2 Review Methods

To review the abstraction of airborne transport of radionuclides, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings, and the description of the geology, geophysics, geochemistry, and meteorological conditions included in the abstraction of airborne transport of radionuclides. Assess the adequacy and consistency of the technical bases for these descriptions, and for incorporating them into the total system performance assessment abstraction for airborne transport of radionuclides. Confirm that models and assumptions used to evaluate airborne transport of radionuclides are consistent with models and assumptions used elsewhere in the license application.

Determine that models used to assess airborne transport of radionuclides are consistent with physical processes generally interpreted from igneous features in the Yucca Mountain region. Verify that models of active igneous processes are consistent with processes generally observed at active igneous features.

Evaluate the technical bases used to assess the effects of engineered repository systems on the consequences of igneous processes.

Verify that the U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate the sufficiency of the geological, geophysical, geochemical, and meteorological data used to support parameters, used in conceptual models, process-level models, and alternative conceptual models, considered in the abstraction of airborne transport of radionuclides.

Determine that the technical bases for these data are adequately justified, and that data used to model processes affecting airborne transport of radionuclides are derived from adequately documented techniques. Such techniques may include site-specific field measurements, natural analog investigations, and laboratory experiments.

Determine that sufficient data are available to integrate features, events, and processes, relevant to airborne transport of radionuclides into process-level models. Determine that appropriate interrelationships and correlations between relevant features, events, and processes are adequately considered in resulting model abstractions.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 3 Data Uncertainty

Examine the technical bases for parameter values, assumed ranges, probability distributions, and bounding assumptions, used in conceptual models, process-level models, and alternative conceptual models, considered in the abstraction of airborne transport of radionuclides. Evaluate the assessment of uncertainty and variability in these parameters, and verify that the technical bases reasonably account for uncertainties and variabilities in the data.

Examine the technical bases used to quantify uncertainty in parameter values observed in site data and the available literature (i.e., data precision), and the uncertainty in abstracting parameter values to process-level models (i.e., data accuracy), to ensure that adequate measures of uncertainty and variability have been considered.

Evaluate the methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Review Method 4 Model Uncertainty

Evaluate the alternative conceptual models used in developing the abstraction for airborne transport of radionuclides. Examine the model parameters considering available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies, and evaluate their consistency.

Determine that uncertainties in abstracted models are adequately defined and documented. Verify that effects of these uncertainties are assessed in the total system performance assessment. Where appropriate, use an alternative total system performance assessment model to evaluate the effects of alternative models on repository performance.

Review Method 5 Model Support

Evaluate the output from the abstraction of airborne transport of radionuclides, and compare the results with an appropriate combination of site characterization data, detailed process-level modeling, laboratory testing, field measurements, and natural analog research.

Determine that inconsistencies between abstracted models and comparative data are explained and quantified. Confirm that the resulting uncertainty is accounted for in the model results.

4.2.1.3.11.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c) and (e)–(g), relating to the airborne transport of radionuclide model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the airborne transport of radionuclides abstraction process;
- Models used to assess airborne transport of radionuclides are consistent with physical processes generally interpreted from igneous features in the Yucca Mountain region and/or observed at active igneous systems;
- Models account for changes in igneous processes that may occur from interactions with engineered repository systems; and
- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or in other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Parameter values used in the safety case to evaluate airborne transport of radionuclides are sufficient and adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;
- Data used to model processes affecting airborne transport of radionuclides are derived from appropriate techniques. These techniques may include site-specific field measurements, natural analog investigations, and laboratory experiments;
- Sufficient data are available to integrate features, events, and processes, relevant to airborne transport of radionuclides into process-level models, including determination of appropriate interrelationships and parameter correlations; and
- Where sufficient data do not exist, the definition of parameter values and associated conceptual models is based on appropriate use of expert elicitation conducted, in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities;
- Parameter uncertainty accounts quantitatively for the uncertainty in parameter values derived from site data and the available literature (i.e., data precision), and the uncertainty introduced by model abstraction (i.e., data accuracy); and
- Where sufficient data do not exist, the definition of parameter values and associated uncertainty is based on appropriate use of expert elicitation conducted, in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches to airborne transport of radionuclides are considered and are consistent with available data and current scientific understandings, and the results and limitations are appropriately considered in the abstraction; and
- Uncertainties in abstracted models are adequately defined and documented, and effects of these uncertainties are assessed in the total system performance assessment.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Models implemented in the airborne transport of radionuclide abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs); and
- Inconsistencies between abstracted models and comparative data are documented, explained, and quantified. The resulting uncertainty is accounted for in the model results.

4.2.1.3.11.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.11.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to the airborne transport of radionuclides and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114 for model abstraction in this section. Technical requirements for conducting a performance assessment in the area of airborne transport of radionuclides have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effect on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.3.11.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.12 Representative Volume

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which representative volume affects the U.S. Department of Energy safety case. Review this model abstraction, considering the risk information evaluated in the "Multiple Barriers" (Section 4.2.1.1). For example, if the U.S. Department of Energy indicates that dilution from well pumping significantly reduces the concentration of radionuclides in water used by the reasonably maximally exposed individual, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the dose to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding

assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the individual protection standard is evaluated using Section 4.2.1.4.1, and compliance with the ground-water protection standard is evaluated using Section 4.2.1.4.3 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.12.1 Areas of Review

This section reviews the representative volume abstraction. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15), and (19), that is relevant to the representative volume abstraction.

The staff will evaluate the following parts of the abstraction of the representative volume, using the review methods and acceptance criteria in Sections 4.2.1.3.12.2 and 4.2.1.3.12.3.

- Description of the geological and hydrological aspects of the representative volume, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;
- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and
- Use of expert elicitation.

4.2.1.3.12.2 Review Methods

To review the abstraction of representative volume, recognize that models used in the total system performance assessments may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of design features, physical phenomena, and couplings, and the description of the geological, hydrological, and geochemical aspects of the abstraction of representative volume that contribute to repository performance.

Assess whether the technical bases for the descriptions of the aspects of dilution from well pumping that are important to repository performance are adequate.

Evaluate whether the description of the aspects of hydrology and geology that may affect the representative volume is adequate. Evaluate whether the descriptions provide transparent and traceable support for the abstraction.

Examine the assumptions, technical bases, data, and models used by the U.S. Department of Energy in the total system performance assessment abstraction of representative volume to determine whether they are appropriate and consistent with other related U.S. Department of Energy abstractions.

Examine how the features, events, and processes, related to representative volume have been included in the total system performance assessment abstraction.

Verify that the U.S. Department of Energy has followed the guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or makes an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Evaluate whether sufficient justification has been provided for climatological and hydrological values used in the safety case, and whether the description of how the data are used, interpreted, and appropriately synthesized into the parameters is sufficiently transparent and traceable.

Evaluate whether sufficient data have been used to support the development of conceptual models used in the abstraction of representative volume as well as the parameters used for each of these models. Determine whether sufficient data have been used in characterizing relevant features, events, and processes and incorporating these features, events, and processes into the abstraction of representative volume.

Determine whether the quality and quantity of data are sufficient for those parameter groups considered important for developing the model abstraction, including groups, such as well classification and design, pumping rates, aquifer parameters, and transport parameters. Where applicable, determine whether reliable statistical estimates can be obtained from the relevant parameter data that can be used to either establish meaningful confidence limits or set meaningful bounding estimates, and determine whether the scales of measured data are appropriately factored into the abstraction.

Review Method 3 Data Uncertainty

Determine whether the use of parameter values, assumed ranges, probability distributions, and bounding assumptions reasonably account for uncertainties and variabilities in the repository system.

Examine the technical bases for parameter values and ranges used in conceptual models, process models, and alternative conceptual models considered in the total system performance assessment abstraction of representative volume. Assess whether these parameter values and distributions are consistent with site characterization data, laboratory experiments, field measurements, and natural analog research.

Assess whether uncertainty is adequately represented in parameters of conceptual models, process models, and alternative conceptual models, considered in developing the total system performance assessment abstraction of representative volume, either through sensitivity analyses, conservative limits, or bounding values supported by data.

Examine the parameters that are identified as being important for the abstraction, and ensure that the level of support for the parameter values and distributions is commensurate with the effect that the parameter has on the total system performance assessment results. To the extent feasible, use an alternative total system performance assessment code to test the sensitivity of the repository performance to the parameter value or model.

Examine the U.S. Department of Energy use of expert elicitation, and confirm that where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of other sources, such as expert elicitation, conducted in accordance with appropriate guidance, such as NUREG–1563 (Kotra, et al., 1996).

Review Method 4 Model Uncertainty

Evaluate whether appropriate alternative conceptual models are used in developing the abstraction for representative volume, and examine the model parameters in the context of available data. Compare the results of alternate process models to results from process models used by the U.S. Department of Energy to assess the uncertainty, limitations, and the degree of conservatism present in the U.S. Department of Energy model. Ascertain whether any limitations identified in the U.S. Department of Energy process model, through this comparison, are adequately accounted for in the U.S. Department of Energy abstraction. Confirm that the U.S. Department of Energy has adequately addressed comments from external reviews of the model abstraction.

Determine whether the results of plausible alternative conceptual models have been considered appropriately in the abstraction, in the context of site characterization data, laboratory experiments, field measurements, natural analog research, and process modeling studies. In particular, use an alternative total system performance assessment model to evaluate the effect of the alternative conceptual model(s) on repository performance.

Review Method 5 Model Support

Evaluate the output from the total system performance assessment model abstraction of representative volume, and determine whether the U.S. Department of Energy compares the results with an appropriate combination of site characterization data, process modeling, laboratory testing, field measurements, and natural analog research. Use detailed models of geochemical, hydrological, and geological processes and an alternative total system performance assessment model to selectively probe the U.S. Department of Energy total system performance assessment analyses, and evaluate selected parts of the U.S. Department of Energy abstraction of representative volume.

4.2.1.3.12.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c), (e)–(g), and 63.30 5, 63.312, and 63.332, relating to the representative volume abstraction. Compliance with the ground-water protection standard is evaluated using Section 4.2.1.4.3 of the Yucca Mountain Review Plan. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the representative volume abstraction process;

- The total system performance assessment model abstraction of representative volume adequately identifies and describes aspects of dilution, from well pumping, that are important to repository performance, and includes the technical bases for these descriptions;

- The description of aspects of hydrology and geology that may affect the representative volume is adequate, and identifies those parameters to which the abstraction is sensitive;

- The total system performance assessment abstraction of representative volume uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions (see Section 4.2.1.4.3 of the Yucca Mountain Review Plan). For example, the approach for modeling dilution from well pumping adequately accounts for observed well design practices, and is consistent with the approach used to model radionuclide transport from the source to the pumping well;

- Sufficient data and technical bases for the inclusion of features, events, and processes, related to representative volume in the total system performance assessment abstraction, are provided; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or in other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Climatological and hydrological values used in the safety case are adequately justified (e.g., well classification and design, aquifer parameters, transport parameters, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;

- Sufficient data (field, laboratory, and/or natural analog data) are available to adequately define relevant parameters and conceptual models, necessary for developing the representative volume abstraction, in total system performance assessment; and

- The quality and quantity of data are sufficient for those parameter groups considered important for developing and calibrating the abstraction model, including groups such as well classification and design, aquifer parameters, and transport parameters.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and/or bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities, and are consistent with the characteristics of the reasonably maximally exposed individual and the representative volume of water defined in 10 CFR Part 63;

- The technical bases for the parameter values and ranges in performance assessment and process models used for estimating representative volume such as pumping rates, well depths, and screen length are consistent with public water supply wells in the town of Amargosa Valley, Nevada, other site characterization data, laboratory experiments, field measurements, and natural analog research, as appropriate;

- Uncertainty is adequately represented in parameters of conceptual models, process models, and alternative conceptual models considered in developing the total system performance assessment abstraction of representative volume either through sensitivity analyses, conservative limits, or bounding values supported by data, as necessary;

- Parameters that are important for the abstraction, through total system performance assessment and sensitivity analyses, are identified;

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with appropriate guidance, such as NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction; and

- Sufficient evidence is provided that existing alternative conceptual models of features and processes have been considered, that the models are consistent with available data (e.g., field, laboratory, and natural analog) and current scientific understanding, and that the effects of these alternative conceptual models on total system performance assessment results are adequately evaluated.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, and/or natural analogs).

4.2.1.3.12.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.12.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114. Technical requirements for conducting a performance assessment, with respect to the representative volume, have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to dilution in ground water due to well pumping, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.115. The required characteristics of the reference biosphere have been satisfied. In particular the U.S. Nuclear Regulatory Commission staff found reasonable expectation that:

- The features, events, and processes used to describe the reference biosphere, the biosphere pathways, the evolution of climate, and the evolution of the geologic setting are consistent with present knowledge of the region, conditions, and past processes in the Yucca Mountain region, as required by 10 CFR 63.305(a)–(d);

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to dilution in ground water due to well pumping, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.312. The required characteristics of the reasonably maximally exposed individual have been satisfied. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The reasonably maximally exposed individual is a hypothetical person living in the accessible environment above the highest radionuclide concentration in the plume of contamination, with a diet and living style representative of people who now live in the town of Amargosa Valley, Nevada. The reasonably maximally exposed individual has metabolic and physical characteristics, and well water usage patterns that meet the requirements of 10 CFR 63.312(a)–(e).

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to dilution in ground water due to well pumping, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.332. The specific requirements for the representative volume have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The U.S. Department of Energy uses average hydrologic characteristics to determine the position and dimension of the ground-water aquifers, and projects radionuclide concentrations for the representative volume such that the highest concentration levels in the contaminant plume are included. The representative volume also contains no more that 3.715×10^9 liters (3,000 acre-feet) and meets any other requirements specified in 10 CFR 63.332(a)(1)–(3).

- To determine the dimensions of the representative volume, the U.S. Department of Energy uses one of the two alternative methods specified in 10 CFR 63.332(b)(1)–(2).

4.2.1.3.12.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.13 Redistribution of Radionuclides in Soil

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which redistribution of radionuclides in soil affects the U.S. Department of Energy safety case. Review this model abstraction considering the risk information determined in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy indicates that redistribution of radionuclides in soil has a strong effect on performance, then perform a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the dose to the reasonably maximally exposed individual, then conduct a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the individual protection standard is evaluated using Section 4.2.1.4.1, and compliance with the ground-water protection standard is evaluated using Section 4.2.1.4.3 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.13.1 Areas of Review

This section reviews redistribution of radionuclides in soil in the biosphere. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15), and (19), that is relevant to the abstraction of redistribution of radionuclides in soil.

The staff will evaluate the following parts of the abstraction of the redistribution of radionuclides in soil, using the review methods and acceptance criteria in Sections 4.2.1.13.2 and 4.2.1.3.13.3:

- Description of the geological, hydrological, pedological, and geochemical aspects of redistribution of radionuclides in soil, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;

- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;

- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;

- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;

- Approaches the U.S. Department of Energy uses to compare total system performance assessment output to process-level model outputs and empirical studies; and

- Use of expert elicitation.

4.2.1.3.13.2 Review Methods

To review the abstraction of the redistribution of radionuclides in soil, recognize that models used in the total system performance assessments may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 Model Integration

Examine the description of features, physical phenomena, and couplings between different models, and determine whether they have been appropriately incorporated in the redistribution of radionuclides in soil abstraction. Confirm that consistent and appropriate assumptions have been made throughout the abstraction.

Examine the aspects of redistribution of radionuclides in soil that have been identified as being important to repository performance, and ensure that these aspects are reasonable. Assess the technical bases for these descriptions, and for incorporating them in the total system performance assessment abstraction of redistribution of radionuclides in soil. Evaluate whether the descriptions provide transparent and traceable support for the abstraction.

Examine how the features, events, and processes related to redistribution of radionuclides in soil, have been included in the total system performance assessment abstraction.

Verify that the U.S. Department of Energy reviews follow guidance, such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or makes an acceptable case for using alternative approaches for peer review and data qualification.

Review Method 2 Data and Model Justification

Ensure that the data on the pedology, hydrology, and soil chemistry used in the total system performance assessment abstraction are based on a combination of techniques that may include laboratory experiments, site-specific field measurements, natural analog research, and process modeling studies. Examine how data were used, interpreted, and synthesized into parameter values, and ensure that it was done appropriately.

Evaluate the sufficiency of the data used to support conceptual models, process-level models, and alternative conceptual models considered in the total system performance assessment abstraction of redistribution of radionuclides in soil. Examine and confirm the sufficiency of the data that support the technical bases, for features, events, and processes related to redistribution of radionuclides in soil, that have been included in the total system performance assessment abstraction.

Review Method 3 Data Uncertainty

Examine the parameter values, ranges, distributions, and bounding assumptions used in conceptual models, process models, and alternative conceptual models considered in the abstraction of redistribution of radionuclides in soil, and evaluate the assessment of uncertainty and variability in these parameters. Evaluate the U.S. Department of Energy's input values by comparison with the corresponding input values in the U.S. Nuclear Regulatory Commission data set, to the extent feasible. However, direct comparison of input values may not be possible if the U.S. Nuclear Regulatory Commission and U.S. Department of Energy models are substantially different.

Examine the technical basis used to support parameter values and ranges, and confirm that the selected parameter ranges and distributions adequately represent the conditions in the Yucca Mountain region.

Assess whether uncertainty is adequately represented in parameters of conceptual models, process models, and alternative conceptual models considered in developing the abstraction of dilution of radionuclides in soil, from surface processes, either through sensitivity analyses, conservative limits, or bounding values supported by data. Assess whether correlations between parameters in the abstraction have been appropriately established.

Evaluate the U.S. Department of Energy determination of the sensitivity of the performance of the system to the parameter value or model and verify that the level of adequacy of data required for justification of parameters or models is commensurate with the impact that the parameter or model has on the performance of the system. To the extent feasible, use alternative total system performance assessment code to test the sensitivity of the repository performance to the parameter value or model.

Examine the U.S. Department of Energy use of expert elicitation, and confirm that where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of other sources, such as expert elicitation, conducted in accordance with appropriate guidance, such as NUREG–1563 (Kotra, et al., 1996).

Review Method 4 Model Uncertainty

Determine whether the U.S. Department of Energy evaluated all appropriate alternative conceptual models for redistribution of radionuclides in soil. Compare the results of alternate process models to results from process models used by the U.S. Department of Energy to assess the uncertainty, limitations, and the degree of conservatism present in the U.S. Department of Energy model. Ascertain whether any limitations identified in the

U.S. Department of Energy process model through this comparison are adequately accounted for in the U.S. Department of Energy abstraction.

Determine whether the results of appropriate alternative conceptual models have been considered in the abstraction in the context of site characterization data, laboratory experiments, field measurements, natural analog research, and process modeling studies. In particular, use an alternative total system performance assessment model to evaluate the effect of the alternative conceptual model(s) on repository performance.

Review Method 5 Model Support

Evaluate the output from the abstraction of redistribution of radionuclides in soil and compare the results with an appropriate combination of site characterization data, process modeling, laboratory testing, field measurements, and natural analog research. As appropriate, the reviewer should use an alternative total system performance assessment code to evaluate selected parts of the U.S. Department of Energy abstraction of redistribution of radionuclides in soil.

4.2.1.3.13.3 Acceptance Criteria

The following acceptance criteria are based on meeting the relevant requirements of 10 CFR 63.114(a)–(c), (e)–(g), 63.305, and 63.312, as they relate to the redistribution of radionuclides in soil abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important features, physical phenomena and couplings between different models, and uses consistent and appropriate assumptions throughout the abstraction of redistribution of radionuclides in the soil abstraction process;

- The total system performance assessment model abstraction identifies and describes aspects of redistribution of radionuclides in soil that are important to repository performance, including the technical bases for these descriptions. For example, the abstraction should include modeling of the deposition of contaminated material in the soil and determination of the depth distribution of the deposited radionuclides;

- Relevant site features, events, and processes have been appropriately modeled in the abstraction of redistribution of radionuclides, from surface processes, and sufficient technical bases are provided; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- Behavioral, hydrological, and geochemical values used in the safety case are adequately justified (e.g., irrigation and precipitation rates, erosion rates, radionuclide solubility values, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided; and

- Sufficient data (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of redistribution of radionuclides in soil in the total system performance assessment.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities, and are consistent with the characteristics of the reasonably maximally exposed individual in 10 CFR Part 63;

- The technical bases for the parameter values and ranges in the total system performance assessment abstraction are consistent with data from the Yucca Mountain region [e.g., Amargosa Valley survey (Cannon Center for Survey Research, 1997), studies of surface processes in the Fortymile Wash drainage basin: applicable laboratory testings: natural analogs: or other valid sources of data. For example, soil types, crop types, plow depths, and irrigation rates should be consistent with current farming practices, and data on the airborne particulate concentration should be based on the resuspension of appropriate material in a climate and level of disturbance similar to that which is expected to be found at the location of the reasonably maximally exposed individual, during the compliance time period;

- Uncertainty is adequately represented in parameters for conceptual models, process models, and alternative conceptual models considered in developing the total system performance assessment abstraction of redistribution of radionuclides in soil, either through sensitivity analyses, conservative limits, or bounding values supported by data, as necessary. Correlations between input values are appropriately established in the total system performance assessment;

- Parameters or models that most influence repository performance based on the performance measure and time period of compliance, specified in 10 CFR Part 63, are identified; and

- Where sufficient data do not exist, the definition of parameter values and conceptual models on appropriate uses of other sources, such as expert elicitation, are conducted in accordance with appropriate guidance, such as NUREG–1563 (Kotra, et al., 1996).

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data, and current scientific understanding, and the results and limitations are appropriately considered in the abstraction; and

- Sufficient evidence is provided that appropriate alternative conceptual models of features, events, and processes have been considered; that the preferred models (if any) are consistent with available data (e.g., field, laboratory, and natural analog) and current scientific understanding; and that the effect on total system performance assessment of uncertainties from these alternative conceptual models has been evaluated.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Models implemented in the abstraction provide results consistent with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, and/or natural analogs).

4.2.1.3.13.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.13.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

These evaluation findings are only with respect to this part of the total system performance assessment model abstraction.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to redistribution of radionuclides in soil, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114. Technical requirements for conducting a performance assessment in the area of redistribution of radionuclides in soil have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effect on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to redistribution of radionuclides in soil, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.305. The required characteristics of the reference biosphere have been satisfied. In particular the U.S. Nuclear Regulatory Commission staff found that:

- The features, events, and processes used to describe the reference biosphere, the biosphere pathways, the evolution of climate, and the evolution of the geologic setting are consistent with present knowledge of the region, conditions, and past processes in the Yucca Mountain region, as required by 10 CFR 63.305(a)–(d).

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to redistribution of radionuclides in soil, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.312. The required characteristics of the reasonably maximally exposed individual have been satisfied. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The reasonably maximally exposed individual is a hypothetical person living in the accessible environment above the highest radionuclide concentration in the plume of contamination, with a diet and living style representative of people who now live in the town of Amargosa Valley, Nevada. The reasonably maximally exposed individual has metabolic and physical characteristics, and well water usage patterns that meet the requirements of 10 CFR 63.312(a) and (b).

4.2.1.3.13.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Cannon Center for Survey Research, University of Nevada. "Identifying and Characterizing the Critical Group Results of a Pilot Study of Amargosa Valley." Las Vegas, Nevada: Cannon Center for Survey Research. 1997.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

4.2.1.3.14 Biosphere Characteristics

To review this model abstraction, evaluate the adequacy of the U.S. Department of Energy license application, relative to the degree to which biosphere characteristics affect the U.S. Department of Energy safety case. Review this model abstraction considering the risk information evaluated in the "Multiple Barriers" Section (4.2.1.1). For example, if the U.S. Department of Energy indicates that biosphere characteristics have a strong effect on performance, then conduct a detailed review of this abstraction. If, on the other hand, the U.S. Department of Energy demonstrates this abstraction to have a minor impact on the dose to the reasonably maximally exposed individual, then perform a simplified review focusing on the bounding assumptions. The review methods and acceptance criteria provided here are for a detailed review. Some of the review methods and acceptance criteria may not be necessary, in a simplified review, for those abstractions that have a minor impact on performance. The demonstration of compliance with the postclosure individual protection standard is evaluated, using Section 4.2.1.4.1 of the Yucca Mountain Review Plan.

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.3.14.1 Areas of Review

This section reviews biosphere characteristics that involve application of the characteristics of the reasonably maximally exposed individual and reference biosphere to transforming estimated concentrations of radionuclides in the biosphere to a dose to the reasonably maximally exposed individual. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (15), and (19) that is relevant to the abstraction of the biosphere characteristics modeling.

The staff will evaluate the following parts of the biosphere characteristics, using review methods and acceptance criteria in Sections 4.2.1.3.14.2 and 4.2.1.3.14.3:

- Description of the ecological, behavioral, geological, hydrological, geochemical, sociological, and economic aspects of biosphere characteristics, and the technical bases the U.S. Department of Energy provides to support model integration across the total system performance assessment abstractions;
- Sufficiency of the data and parameters used to justify the total system performance assessment model abstraction;
- Methods the U.S. Department of Energy uses to characterize data uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;

- Methods the U.S. Department of Energy uses to characterize model uncertainty, and propagate the effects of this uncertainty, through the total system performance assessment model abstraction;

- Approaches the U.S. Department of Energy uses to compare output from the total system performance assessment model abstraction to process-level outputs and empirical studies; and

- Use of expert elicitation.

4.2.1.3.14.2 Review Methods

For the abstraction of biosphere characteristics, recognize that models used in the total system performance assessment may range from highly complex process-level models to simplified models, such as response surfaces or look-up tables. Evaluate model adequacy, regardless of the level of complexity.

Review Method 1 System Description and Model Integration

Determine whether the abstraction includes all important site features, physical phenomena, and couplings, and whether consistent and appropriate assumptions have been used through the abstraction;

Verify that the description is adequate, and that the conditions and assumptions in the total system performance assessment abstraction are consistent with the body of data, presented in the description. Determine whether the technical bases for these descriptions, and for incorporating them in the abstraction, are appropriate. Evaluate whether the descriptions provide transparent and traceable support for the abstraction;

Consider important physical phenomena and couplings with other abstractions, and examine them for consistency; and

Determine whether the U.S. Department of Energy has used an acceptable approach for peer reviews, such as the guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or makes an acceptable case for using alternative approaches.

Review Method 2 Data and Model Justification

Determine whether the parameter values used in the safety case are adequately justified, and consistent with the definition of the reasonably maximally exposed individual in 10 CFR 63.312. Evaluate how the data were used, interpreted, and appropriately synthesized into the parameters.

Evaluate the sufficiency of the data and parameters used to support the modeling of features, events, and processes in conceptual models, process-level models, and alternative conceptual models considered in the total system performance assessment biosphere characteristics. When evaluating alternate conceptual models of the biosphere or biosphere processes, the reviewer should recognize that 10 CFR 63.305 and 63.312 place a number of constraints on

both the biosphere and the characteristics of the reasonably maximally exposed individual. For example, 10 CFR 63.312 limits the diet and living style of the reasonably maximally exposed individual to be representative of the current population of the town of Amargosa Valley, Nevada. Therefore, evaluation of alternate conceptual models should focus on exploring the variability and uncertainty in the features, events, and processes incorporated in the biosphere abstraction , mindful of the regulatory constraints. Evaluation of behavior and characteristics of the reasonably maximally exposed individual should emphasize interpretation of survey studies of the current residents of the Town of Amargosa Valley and how uncertainty and variability in the data are used to derive mean values.

Ensure that the data used in the U.S. Department of Energy total system performance assessment abstraction are based on a combination of techniques, that may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. Investigate the effects of any differences in model and implementation approach on dose results by executing an alternative total system performance assessment code with the U.S. Department of Energy input parameters, and by comparing calculated dose results with those reported by the U.S. Department of Energy. Confirm that any differences or identified limitations in model selection and implementation, that significantly decrease dose results, are adequately justified in the U.S. Department of Energy analysis.

Review Method 3 Data Uncertainty

Examine the technical bases for parameter values and ranges used in conceptual models, process-level models, and alternative conceptual models considered in the total system performance assessment biosphere characteristics. When evaluating alternate conceptual models of the biosphere or biosphere processes, the reviewer should recognize that 10 CFR 63.305 and 63.312 put a number of constraints on both the biosphere and the characteristics of the reasonably maximally exposed individual. For example, 10 CFR 63.312 limits the diet and lifestyle of the reasonably maximally exposed individual to be representative of the current population of the Town of Amargosa Valley, Nevada. Therefore, evaluation of alternate conceptual models should focus on exploring the variability and uncertainty in the features, events, and processes incorporated in the biosphere abstraction, mindful of the regulatory constraints. Evaluation of behavior and characteristics of the reasonably maximally exposed individual should emphasize interpretation of local survey studies of the current residents of the Town of Amargosa Valley and how uncertainties and variability in the data are used to derive mean values.

Evaluate the assessment of uncertainty and variability in parameters. Verify that the U.S. Department of Energy has a technically defensible basis to support the determination that the diet and living style of the reasonably maximally exposed individual are based on the mean values of data obtained from surveys of residents of the Town of Amargosa Valley, Nevada, as specified in 10 CFR 63.312.

Evaluate whether the parameters, values, and distributions used to describe features, events, and processes of the biosphere are technically defensible, and are consistent with present knowledge of conditions in the region surrounding Yucca Mountain.

Evaluate the effects of including uncertainty and variability ranges (for important parameters) in total system performance assessment runs. Tests can provide information on the effects of including these ranges in the total system performance assessment (e.g., sensitivity and uncertainty analyses), and/or demonstrate the effects different ranges may have on dose results. Verify that any differences or identified limitations in the U.S. Department of Energy analysis that significantly decrease dose results are adequately justified.

Evaluate methods used by the U.S. Department of Energy in conducting expert elicitation to define parameter values.

Examine the sensitivity of total system performance assessment results to identify parameter differences by comparing total system performance assessment results based on the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission parameter selections. Emphasize those parameters known to be important in biosphere characteristics modeling, such as consumption rates, intake-to-dose conversion factors, plant and animal transfer factors, mass-loading factors, and crop interception fractions.

Review Method 4 Model Uncertainty

Examine the model parameters in the context of available site characterization data, laboratory experiments, field measurements, natural analog research, and process-level modeling studies. To the extent practical and necessary, use an alternative total system performance assessment model to evaluate selected parts of the U.S. Department of Energy biosphere characteristics, and evaluate the effect of the alternative conceptual model(s) on repository performance. When evaluating alternate conceptual models of the biosphere or biosphere processes, the reviewer should recognize that 10 CFR 63.305 and 63.312 put a number of constraints on both the biosphere and selection of the reasonably maximally exposed individual. For example, 10 CFR 63. 312 limits the diet and living style of the reasonably maximally exposed individual to be representative of the current residents of the Town of Amargosa Valley, Nevada. Therefore, evaluation of alternate conceptual models should focus on exploring the variability and uncertainty in the features, events, and processes incorporated in the biosphere abstraction, mindful of the regulatory constraints. Evaluation of behavior and characteristics of the reasonably maximally exposed individual should emphasize interpretation of survey studies of the residents of the Town of Amargosa Valley and how uncertainty and variability in the data are used to derive mean values.

Determine whether sufficient evidence has been presented that existing alternative conceptual models of processes that are important to performance have been considered in the biosphere characteristics.

Review Method 5 Model Support

Evaluate the output from the biosphere characteristics modeling and compare the results with an appropriate combination of site characterization data, process-level modeling, laboratory testing, field measurements, and natural analog research. Examine the sensitivity analyses used to support the biosphere characteristics modeling in the total system performance assessment. To the extent practical and necessary, use an alternative total system performance assessment code to evaluate selected parts of the U.S. Department of Energy

biosphere characteristics modeling. Compare the U.S. Department of Energy biosphere dose conversion factors with the results of dose modeling using a code, such as GENII-S (Leigh, et al., 1993) and the U.S. Department of Energy input parameter data. The reviewer should conduct confirmatory runs, using alternative dose calculation codes and the U.S. Department of Energy input parameters, as necessary.

4.2.1.3.14.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.114(a)–(c), (e)–(g), 63.305, and 63.312 as they relate to biosphere characteristics modeling.

U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed safety case.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

- Total system performance assessment adequately incorporates important site features, physical phenomena, and couplings, and consistent and appropriate assumptions throughout the biosphere characteristics modeling abstraction process;

- The total system performance assessment model abstraction identifies and describes aspects of the biosphere characteristics modeling that are important to repository performance, and includes the technical bases for these descriptions. For example, the reference biosphere should be consistent with the arid or semi-arid conditions in the vicinity of Yucca Mountain;

- Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the U.S. Department of Energy should ensure that the modeling of features, events, and processes, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other total system performance assessment abstractions; and

- Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or in other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2 Data Are Sufficient for Model Justification.

- The parameter values used in the safety case are adequately justified (e.g., behaviors and characteristics of the residents of the Town of Amargosa Valley, Nevada, characteristics of the reference biosphere, etc.) and consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided; and

- Data are sufficient to assess the degree to which features, events, and processes related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the U.S. Department of Energy should demonstrate that features, events, and processes, which describe the biosphere, are consistent with present knowledge of conditions in the region, surrounding Yucca Mountain. As appropriate, the U.S. Department of Energy sensitivity and uncertainty analyses (including consideration of alternative conceptual models) are adequate for determining additional data needs, and evaluating whether additional data would provide new information that could invalidate prior modeling results and affect the sensitivity of the performance of the system to the parameter value or model.

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities, and are consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63;

- The technical bases for the parameter values and ranges in the abstraction, such as consumption rates, plant and animal uptake factors, mass-loading factors, and biosphere dose conversion factors, are consistent with site characterization data, and are technically defensible;

- Process-level models used to determine parameter values for the biosphere characteristics modeling are consistent with site characterization data, laboratory experiments, field measurements, and natural analog research;

- Uncertainty is adequately represented in parameter development for conceptual models and process-level models considered in developing the biosphere characteristics modeling, either through sensitivity analyses, conservative limits, or bounding values supported by data, as necessary. Correlations between input values are appropriately established in the total system performance assessment, and the implementation of the abstraction does not inappropriately bias results to a significant degree;

- Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with appropriate guidance, such as NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their uses; and

- Parameters or models that most influence repository performance, based on the performance measure and time period of compliance specified in 10 CFR Part 63, are identified.

Acceptance Criterion 4 Model Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations of alternative modeling approaches are appropriately considered in the abstraction. Staff should evaluate alternate conceptual models of the biosphere or biosphere processes, recognizing that 10 CFR 63.305 and 63.312 place a number of constraints on both the biosphere and the characteristics of the reasonably maximally exposed individual. Alternate conceptual models focus on exploring the variability and uncertainty in the physical features, events, and processes, mindful of the regulatory constraints. Evaluation of behavior and characteristics of the reasonably maximally exposed individual emphasizes understanding the characteristics of the current residents of the Town of Amargosa Valley, and uncertainty and variability in the data used to derive mean values; and

- Sufficient evidence is provided that existing alternative conceptual models of features and processes that are important to performance, such as plant uptake of radionuclides from soil, soil resuspension, and the inhalation dose model for igneous events, have been considered.

Acceptance Criterion 5 Model Abstraction Output Is Supported by Objective Comparisons.

- Dose calculations pertaining to this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, and/or natural analogs).

4.2.1.3.14.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.3.14.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.114, regarding biosphere characteristics modeling in performance assessment. In particular, the U.S. Nuclear Regulatory Commission staff found reasonable expectation that:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternative conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f); and

- Adequate technical bases have been provided for models used in the performance assessment, as required by 10 CFR 63.114(h).

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.305. The required characteristics of the reference biosphere have been justified. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The features, events, and processes used to describe the reference biosphere, the biosphere pathways, the evolution of climate, and the evolution of the geologic setting are consistent with present knowledge of the region, conditions, and past processes in the Yucca Mountain region, as required by 10 CFR 63.305(a); and

- Biosphere pathways are consistent with arid or semi-arid conditions as required by 10 CFR 63.305(b);

- Climate evolution is consistent with the geologic record of natural climate change in the region surrounding the Yucca Mountain site as required by 10 CFR 63.305(c); and

- Changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology are assumed constant at the time of license application and changes are not projected into the future as required in 10 CFR 63.305(d).

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to biosphere characteristics modeling and the characteristics of the reasonably maximally exposed individual, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.312. The required characteristics of the reasonably maximally exposed individual have ben satisfied. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The reasonably maximally exposed individual is a hypothetical person living in the accessible environment above the highest radionuclide concentration in the plume of contamination, with a diet and living style representative of people who now live in the Town of Amargosa Valley, Nevada. The reasonably maximally exposed individual has metabolic and physical characteristics, and well water usage patterns that meet the requirements of 10 CFR 63.312(a)–(e).

4.2.1.3.14.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, "Generic Technical Position on Peer Review for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988a.

———. NUREG–1298, "Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories." Washington, DC: U.S. Nuclear Regulatory Commission. 1988b.

Kotra, J.P., et al. NUREG–1563, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program." Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

Leigh, C.D., et al. "User's Guide for GENII-S: A Code for Statistical and Deterministic Simulation of Radiation Doses to Humans from Radionuclides in the Environment." SAND 91-0561. Albuquerque, New Mexico: Sandia National Laboratories. 1993.

4.2.1.4 Demonstration of Compliance with the Postclosure Public Health and Environmental Standards

4.2.1.4.1 Demonstration of Compliance with the Postclosure Individual Protection Standard

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.4.1.1 Areas of Review

This section reviews the analysis of repository performance that demonstrates compliance with the postclosure individual protection standard. Reviewers will also evaluate the information, required by 10 CFR 63.21(c)(11) and (12). The review of compliance with the standards for ground-water protection as required by 10 CFR 63.331 and 63.332 will be conducted using Section 4.2.1.4.3 of the Yucca Mountain Review Plan.

The staff will evaluate the following parts of the analysis of repository performance that demonstrates compliance with the postclosure individual protection standard, using the review methods and acceptance criteria in Sections 4.2.1.4.1.3 and 4.2.1.4.1.4:

- Scenario classes that have been included in a set of total system performance assessment calculations;
- Calculations of the annual dose curve; and
- Credibility of the total system performance assessment results, based on an understanding of assumptions and parameters of the total system performance assessment and consideration of uncertainties of the analysis.

4.2.1.4.1.2 Review Methods

Review Method 1 Scenarios Used in the Calculation of the Annual Dose as a Function of Time

Confirm that the estimates of the annual dose, as a function of time, include all scenario classes that have been determined to be sufficiently probable or to have a sufficient effect on overall performance, that they could not be screened from the total system performance assessment analyses, based on the results of the review conducted using Section 4.2.1.2 of the Yucca Mountain Review Plan.

Confirm that the U.S. Department of Energy calculation of the annual dose curve appropriately sums the contribution of each of the scenario classes. Verify that the contribution to the annual dose from each scenario class calculation properly accounts for the effects that the time of occurrence of the disruptive events comprising the scenario class has on the consequences. Also, verify that the annual probability of occurrence of the events used to calculate the contribution to the annual dose is consistent with the results of the review conducted, using Section 4.2.1.2.2 of the Yucca Mountain Review Plan. The probabilities of occurrence of all scenario classes included in the annual dose curve should sum to one.

Review Method 2 Demonstration That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Does Not Exceed the Postclosure Individual Protection Standard

Confirm that the U.S. Department of Energy has conducted a sufficient number of realizations for each scenario class using their total system performance assessment computer code to ensure that the results of the total system performance assessment are statistically stable. Use simulations with an alternative total system performance assessment code to help confirm that the appropriate number of realizations were performed to achieve stable results.

Confirm that repository performance and the performance of individual components or subsystems are consistent and reasonable. Verify that results of alternative total system performance assessment code analyses confirm estimates of repository performance. The results should be consistent with the results examined, using Section 4.2.1.1 "System Description and Demonstration of Multiple Barriers" of the Yucca Mountain Review Plan.

Confirm that the total system performance assessment results show that the repository performance results in an annual dose, to the reasonably maximally exposed individual in any year during the compliance period, which does not exceed the postclosure individual protection standard.

Review Method 3 Credibility of the Total System Performance Assessment Code Representation of Repository Performance

In coordination with the reviewers of the model abstractions (using Section 4.2.1.3 of the Yucca Mountain Review Plan), ensure that assumptions and parameters used in the total system performance assessment are acceptable. Verify that assumptions made within the total system

performance assessment are consistent among different modules of the U.S. Department of Energy total system performance assessment code. Confirm that the use of assumptions and parameter values that differ among modules of the U.S. Department of Energy total system performance assessment code is adequately documented.

Confirm that the total system performance assessment code is properly verified, such that there is confidence that the code is modeling the physical processes in the repository system in the manner that was intended (i.e., individual modules of the total system performance assessment code produce results consistent with the results of the reviews of Sections 4.2.1.1, 4.2.1.2, and 4.2.1.3 of the Yucca Mountain Review Plan). Verify that the transfer of data between modules of the code is conducted properly (i.e., units are the same in both modules and the data are assigned to proper variables). Confirm the results from the outputs of individual models using an alternative total system performance assessment code.

Examine the U.S. Department of Energy estimate of the uncertainty in the performance assessment results (i.e., timing and magnitude of the annual dose), and confirm that it is reasonable, considering the uncertainties in modeling assumptions and parameter values reviewed, using Sections 4.2.1.2 and 4.2.1.3 of the Yucca Mountain Review Plan. Use an alternative total system performance assessment code to help confirm the results for the individual modules.

Confirm that the U.S. Department of Energy has used an appropriate approach for sampling parameters in the total system performance assessment code across their ranges of uncertainty.

4.2.1.4.1.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.113(b) and 63.114, relating to the analysis of repository performance, that demonstrates compliance with the postclosure individual protection standard.

Acceptance Criterion 1 Scenarios Used in the Calculation of the Annual Dose as a Function of Time Are Adequate.

- The annual dose as a function of time includes all scenario classes that have been determined to be sufficiently probable, or to have a sufficient effect on overall performance that they could not be screened from the total system performance assessment analyses; and

- The calculation of the annual dose curve appropriately sums the contribution of each of the disruptive event scenario classes. The contribution to the annual dose from each scenario class calculation properly accounts for the effects that the time of occurrence of the disruptive events comprising the scenario class has on the consequences. The annual probability of occurrence of the events used to calculate the contribution to the annual dose is consistent with the results of the scenario analysis. The probabilities of occurrence of all scenario classes, included in calculating the annual dose curve, sum to one.

Acceptance Criterion 2 An Adequate Demonstration Is Provided That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Does Not Exceed the Exposure Standard.

- 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;
- The annual dose curve includes confidence intervals (e.g., 95th and 5th percentile) to represent the uncertainty in the dose calculations;
- Repository performance and the performance of individual components or subsystems are consistent and reasonable; and
- The total system performance assessment results confirm that the repository performance results in annual dose, to the reasonably maximally exposed individual, in any year, during the compliance period, that does not exceed the postclosure individual protection standard.

Acceptance Criterion 3 The Total System Performance Assessment Code Provides a Credible Representation of Repository Performance.

- Assumptions made within the total system performance assessment code are consistent among different modules of the code. The use of assumptions and parameter values that differ among modules of the code is adequately documented;
- The total system performance assessment code is properly verified, such that there is confidence that the code is modeling the physical processes in the repository system in the manner that was intended. The transfer of data between modules of the code is conducted properly;
- The estimate of the uncertainty in the performance assessment results is consistent with the model and parameter uncertainty; and
- The total system performance assessment sampling method ensures that sampled parameters have been sampled across their ranges of uncertainty.

4.2.1.4.1.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.4.1.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the

requirements of 10 CFR 63.113(b). The performance objectives for the geologic repository after permanent closure have been met. In particular:

- The engineered barrier system is designed so that, working in combination with the natural barriers, the annual dose to the reasonably maximally exposed individual meets the postclosure individual protection standard during the first 10,000 years after permanent closure, as required by 10 CFR 63.113(b); and

- The ability of the geologic repository to limit radiological exposures has been demonstrated, through a performance assessment, meeting the requirements of 10 CFR 63.114, and uses the reference biosphere defined in 10 CFR 63.305(a)–(e), the reasonably maximally exposed individual as defined in 10 CFR 63.312(a)–(e), and excludes the effects of human intrusion.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found that they satisfy the requirements of 10 CFR 63.114(a). Technical requirements for conducting a performance assessment have been met. In particular:

- Appropriate data from the site and surrounding region, uncertainties and variabilities in parameter values, and alternate conceptual models have been used in the analyses, in compliance with 10 CFR 63.114(a)–(c);

- The U.S. Department of Energy has considered those events that have at least one chance in 10,000 of occurring over 10,000 years, in compliance with 10 CFR 63.114(d);

- Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(e);

- Specific degradation, deterioration, and alteration processes have been included in the analyses, taking into consideration their effects on annual dose, and appropriate technical bases have been provided for inclusion or exclusion, in compliance with 10 CFR 63.114(f).

- Adequate technical bases are provided for models used in the performance assessment, as required by 10 CFR 63.114(g).

4.2.1.4.1.5 References

None.

4.2.1.4.2 Demonstration of Compliance with the Human Intrusion Standard

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.4.2.1 Areas of Review

This section reviews the analysis of performance in the event of limited human intrusion. Reviewers will also evaluate the information, required by 10 CFR 63.21(c)(13).

The staff will evaluate the following parts of the analysis of performance, in the event of limited human intrusion, using the review methods and acceptance criteria in Sections 4.2.1.4.2.2 and 4.2.1.4.2.3:

- Results of the separate total system performance assessment performed for human intrusion;
- Technical bases and associated analyses used to determine the time of occurrence of human intrusion without recognition by the drillers; and
- Credibility of the evaluation of human intrusion based on an understanding of assumptions and parameters of the total system performance assessment, characteristics of the intrusion event, and consideration of uncertainties in the analysis.

4.2.1.4.2.2 Review Methods

Review Method 1 Evaluation of the Time of Occurrence of an Intrusion Event

Verify that the technical bases and associated analyses used to determine the time of occurrence of human intrusion without recognition by the drillers are adequate and appropriate. For example, the technical bases include analyses of the time to which the engineered barrier system has degraded to the point at which a driller can intercept the repository but not recognize it.

Review Method 2 Evaluation of An Intrusion Event That Demonstrates That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Is Acceptable

If intrusion occurs within the regulatory timeframe, confirm that the total system performance assessment for human intrusion is performed separately from the overall total system performance assessment, and meets the requirements for performance assessments, specified in 10 CFR 63.114.

Verify that the total system performance assessment for human intrusion is identical to the total system performance assessment for individual protection, except that it assumes the occurrence of a postulated human intrusion event with characteristics, as defined in 10 CFR 63.322 and excludes the consideration of unlikely (Commission will define in future rulemaking) natural features, events, and processes.

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

Verify that the estimated repository performance is reasonable and consistent with the results evaluated during the review, using Section 4.2.1.4 of the Yucca Mountain Review Plan, and with the characteristics of the postulated intrusion event. Use results of an alternative total system performance assessment code to confirm repository performance with the postulated intrusion event.

Verify that the annual dose curve for limited human intrusion confirms that the repository system meets performance objectives, specified in 10 CFR 63.321, for limited human intrusion events.

Review Method 3 The Total System Performance Assessment Code Representation of the Intrusion Event

In coordination with the reviewers of the model abstractions (using Section 4.2.1.3 of the Yucca Mountain Review Plan), ensure that assumptions made within the total system performance assessment for evaluating the postulated intrusion event are consistent among different modules of the code. Verify that any use of assumptions and parameter values that differ among modules of the code is adequately documented.

Confirm that the total system performance assessment code is properly verified, such that there is confidence that the code is modeling the physical processes in the repository system in the manner that is consistent with the characteristics of the postulated intrusion event. Verify that the transfer of data between modules of the code is conducted properly (i.e., units are the same in both modules and the data are assigned to proper variables). Use an alternative total system performance assessment code to confirm the U.S. Department of Energy results for the outputs of individual modules.

Verify that the estimate of the uncertainty in the performance assessment results (i.e., timing and magnitude of annual dose) is consistent with the uncertainties considered in the characteristics of the postulated intrusion event and the uncertainties (i.e., model and parameter uncertainty) evaluated, using Sections 4.2.1.2 and 4.2.1.3 of the Yucca Mountain Review Plan.

Confirm that the total system performance assessment sampling method ensures that sampled parameters of the postulated intrusion event have been sampled across their ranges of uncertainty.

4.2.1.4.2.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.113(d), relating to analysis of performance in the event of limited human intrusion.

Acceptance Criterion 1 Evaluation of the Time of an Intrusion Event.

- The technical basis and associated analyses adequately support the selection of time of occurrence of human intrusion, as specified in 10 CFR 63.321.

Acceptance Criterion 2 Evaluation of an Intrusion Event Demonstrates That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Is Acceptable.

- The total system performance assessment for human intrusion is performed separately from the overall total system performance assessment, and meets the requirements for performance assessments, specified in 10 CFR 63.114.
- The total system performance assessment for human intrusion is identical to the total system performance assessment for individual protection, except that it assumes the occurrence of a postulated human intrusion event with characteristics, as defined in 10 CFR 63.322;
- A sufficient number of realizations has been run using the total system performance assessment code, to ensure that the results of the calculations are statistically stable;
- The estimated repository performance is reasonable and consistent with the analysis of overall repository performance, and with the characteristics of the postulated intrusion event; and
- The annual dose curve for limited human intrusion confirms that the repository system meets performance objectives, specified in 10 CFR 63.321, for limited human intrusion events.

Acceptance Criterion 3 The Total System Performance Assessment Code Provides a Credible Representation of the Intrusion Event.

- Assumptions made within the total system performance assessment for evaluating the postulated intrusion event are consistent among different modules of the code. The use of assumptions and parameter values that differ among modules of the code is adequately documented;
- The total system performance assessment code for evaluating human intrusion is properly verified, such that there is confidence that the code is modeling the physical processes in the repository system in the manner that is consistent with the characteristics of the postulated intrusion event. The transfer of data between modules of the code is conducted properly;
- The estimate of the uncertainty in the performance assessment results is consistent with the uncertainties considered in the characteristics of the postulated intrusion event, and with model and parameter uncertainty; and
- The sampling method used in the total system performance assessment ensures that sampled parameters of the postulated intrusion event have been sampled across their ranges of uncertainty.

4.2.1.4.2.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.4.2.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found, with reasonable expectation, that they satisfy the requirements of 10 CFR 63.113(d). The requirements for demonstrating repository performance, in the event of limited human intrusion, have been met.

4.2.1.4.2.5 References

None.

4.2.1.4.3 Analysis of Repository Performance that Demonstrates Compliance with the Separate Ground-Water Protection Standards

Review Responsibilities—High-Level Waste Branch and Environmental and Performance Assessment Branch

4.2.1.4.3.1 Areas of Review

This section reviews analysis of repository performance that demonstrates compliance with the separate ground-water protection standards. Reviewers will also evaluate information, required by 10 CFR 63.21(c)(1), (9), (14), and (15).

The staff will evaluate the following parts of the analysis of repository performance that demonstrate compliance with the separate ground-water protection standards, using the review methods and acceptance criteria in Sections 4.2.1.4.3.2 and 4.2.1.4.3.3:

- Calculations of the concentrations of specified radionuclides and doses as functions of time; and
- Credibility and consistency of the methods and assumptions used to identify the location of highest concentration of radionuclides in the accessible environment and to estimate the physical dimensions of the 3,000 acre-feet representative volume of ground water.

4.2.1.4.3.2 Review Methods

Review Method 1 Demonstration that the Ground-Water Radioactivity and Doses at Any Year During the Compliance Period Do Not Exceed the Separate Ground-Water Protection Standard

Confirm that the U.S. Department of Energy has provided an estimate of ground-water radioactivity for the representative volume of ground water that includes combined radium-226

and radium-228, gross alpha activity (including radium-226 but excluding radon and uranium), and combined beta and photon emitting radionuclides.

Verify that the average level of radioactivity in the representative volume of ground water is calculated using methods, assumptions, models, and data that are consistent with the performance assessment calculations for the undisturbed case over the period of 10,000 years after disposal (the separate ground-water protection standard does not consider unlikely events). Ensure that the calculated ground-water radioactivity is supported by adequate technical bases that are consistent with those evaluated in the performance assessment abstractions for "Flow Paths in the Saturated Zone" (Section 4.2.1.3.8), "Radionuclide Transport in the Saturated Zone" (Section 4.2.1.3.9), and the "Representative Volume" (Section 4.2.1.3.12).

Compare the calculated level of ground-water radioactivity at any year during the 10,000-year compliance period to the limits established in 10 CFR 63.331.

Review Method 2 Methods and Assumptions used to Determine the Location and Shape of the Representative Volume of Ground Water

Verify that the representative volume of ground water is located along the radionuclide migration path from the proposed repository at Yucca Mountain to the accessible environment.

Compare the hydrologic and transport parameters used to determine the location of the representative volume of ground water. Confirm that assumptions, methods, models, and data are consistent with those used in repository performance assessment calculations for the undisturbed case over the period of 10,000 years after disposal. Verify that the calculations are supported by an adequate technical basis that is consistent with performance assessment abstractions for "Flow Paths in the Saturated Zone" (Section 4.2.1.3.8) and "Radionuclide Transport in the Saturated Zone" (Section 4.2.1.3.9).

Confirm that the representative volume of ground water is located in such a way that it includes the highest concentration level in the plume of contamination. Verify that the location of the highest concentration of radionuclides in the plume of contamination used for the location of the representative volume of ground water is consistent with the requirements used to define characteristics of the reasonably maximally exposed individual in 10 CFR 63.312(a). Confirm that the locations of the representative volume of ground water and the highest concentration level in the plume of contamination are consistent with the performance assessment model abstraction "Representative Volume" (Section 4.2.1.3.12).

Review Method 3 Methods and Assumptions Used in Calculating the Physical Dimensions of the Representative Volume of Ground Water

Confirm that the representative volume of ground water is drawn from an aquifer containing less than 10,000 milligrams of total dissolved solids per liter of water, and contains no more than 3,000 acre-feet (3.714×10^9 liters).

Verify that the physical dimensions of the representative volume are determined using one of the methods defined in 10 CFR 63.332. Depending on the method selected, confirm that

information such as well characteristics, pumping rates, ground-water flow direction, and screening intervals are consistent with those used in repository performance assessment calculations for the undisturbed case over the period of 10,000 years after disposal, and the calculations are supported by an adequate technical basis. For example, evaluate whether the levels of ground-water radioactivity in the representative volume of ground water are determined using modeling approaches and parameters that are consistent with those used in the performance assessment abstractions for "Flow Paths in the Saturated Zone" (Section 4.2.1.3.8) and "Radionuclide Transport in the Saturated Zone" (Section 4.2.1.3.9).

Ensure that the representative volume of ground water is consistent with the water usage characteristics of the reasonably maximally exposed individual defined in 10 CFR 63.312(c) and 63.312(d). For example, verify that the representative volume of ground water is consistent with that used in analyses in "Representative Volume" (Section 4.2.1.3.12).

4.2.1.4.3.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements of 10 CFR 63.331, relating to compliance with the separate standards for protection of ground water, and 10 CFR 63.332, relating to the representative volume of ground water.

Acceptance Criterion 1 An Adequate Demonstration is Provided That the Expected Concentration of Combined Radium-226 and Radium-228, Expected Concentration of Specified Alpha-emitting Radionuclides, and Expected Whole Body or Organ-specific Doses from any Photon- or Beta-emitting Radionuclides at Any Year During the Compliance Period Do Not Exceed the Separate Ground-Water Protection Standards.

- The U.S. Department of Energy has provided an estimate of ground-water radioactivity for the representative volume of ground water that includes combined radium-226 and radium-228, gross alpha activity (including radium-226 but excluding radon and uranium), and combined beta- and photon-emitting radionuclides.

- The level of ground-water radioactivity in the representative volume of ground water is calculated using methods, assumptions, models, and data that are consistent with the repository performance assessment calculations for the undisturbed case over the period of 10,000 years after disposal, and the calculations are supported by an adequate technical basis. For example, the level of ground-water radioactivity in the representative volume of ground water is determined using modeling approaches and parameters that are consistent with those evaluated in the performance assessment abstractions for "Flow Paths in the Saturated Zone" (Section 4.2.1.3.8) and "Radionuclide Transport in the Saturated Zone" (Section 4.2.1.3.9), and using dilution analyses consistent with those in the "Representative Volume" (Section 4.2.1.3.12) model abstraction.

- The average level of ground-water radioactivity at any year during the 10,000-year compliance period meets the limits specified in 10 CFR 63.331.

Acceptance Criterion 2 The Methods and Assumptions Used to Determine the Position of the Representative Volume of Ground Water are Credible and Consistent, and the Representative Volume of Ground Water Includes the Highest Concentration Level in the Plume of Contamination in the Accessible Environment.

- The representative volume of ground water is located along the radionuclide migration path from the proposed repository at Yucca Mountain to the accessible environment as defined in 10 CFR 63.302.

- The location of the representative volume of ground water is determined using average hydrologic parameters that are consistent with those used in repository performance assessment calculations for the undisturbed case over the period of 10,000 years after disposal, and the calculations are supported by an adequate technical basis. For example, the levels of ground-water radioactivity in the representative volume of ground water are determined using modeling approaches and parameters that are consistent with those evaluated in the performance assessment abstractions for "Flow Paths in the Saturated Zone" (Section 4.2.1.3.8) and "Radionuclide Transport in the Saturated Zone" (Section 4.2.1.3.9).

- The representative volume of ground water is located in such a way that it includes the highest concentration level in the plume of contamination. In this respect, the location of the highest concentration of radionuclides in the plume of contamination used for the location of the representative volume of ground water is consistent with the requirements used to define characteristics of the reasonably maximally exposed individual in 10 CFR 63.312(a). For example, the locations of the representative volume of ground water and the highest concentration level in the plume of contamination are consistent with those used in analyses in "Representative Volume" (Section 4.2.1.3.12).

Acceptance Criterion 3 The Methods and Assumptions Used to Calculate the Physical Dimensions of the Representative Volume of Ground Water are Credible and Consistent.

- The representative volume of ground water is drawn from an aquifer containing less than 10,000 milligrams of total dissolved solids per liter of water, and contains no more than 3,000 acre-feet (3.714×10^9 liters).

- The physical dimensions of the representative volume are determined using one of the methods defined in 10 CFR 63.332. Depending on the method selected, information including, but not limited to, well characteristics, pumping rates, ground-water flow direction, and screening intervals are consistent with those used in repository performance assessment calculations for the undisturbed case over the period of 10,000 years after disposal, and the calculations are supported by an adequate technical basis. For example, the levels of ground-water radioactivity in the representative volume of ground water are determined using modeling approaches and parameters that are consistent with those evaluated in the performance assessment abstractions for "Flow Paths in the Saturated Zone" (Section 4.2.1.3.8) and "Radionuclide Transport in the Saturated Zone" (Section 4.2.1.3.9).

- The representative volume of ground water is consistent with the water usage characteristics of the reasonably maximally exposed individual defined in 10 CFR 63.312(c) and 63.312(d). For example, the representative volume of ground water is consistent with that used in analyses in "Representative Volume" (Section 4.2.1.3.12).

4.2.1.4.3.4 Evaluation Findings

If the license application provides sufficient information and the regulatory acceptance criteria in Section 4.2.1.4.3.3 are appropriately satisfied, the staff concludes that this evaluation is complete. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, and has found that they satisfy the requirements of 10 CFR 63.331 and 10 CFR 63.332. The requirements for demonstrating compliance with the ground-water protection standards have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The average concentrations of combined radium-226 and radium-228, gross alpha activity (including radium-226 but excluding radon and uranium) and combined beta and photon emitting radionuclides meet the limits required by 10 CFR 63.331.

U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other docketed material, relevant to dilution in ground water due to well pumping, and has found that they satisfy the requirements of 10 CFR 63.332. The specific requirements for the representative volume of ground water have been met. In particular, the U.S. Nuclear Regulatory Commission staff found that:

- The representative volume of ground water is drawn from an aquifer containing less than 10,000 milligrams of total dissolved solids per liter of water to meet a given water demand. Average hydrologic characteristics that are consistent with the repository performance assessment calculations are used to determine the position and dimension of the ground-water aquifers, and projects average radionuclide concentrations for the representative volume such that the highest concentration levels in the contaminant plume are included. The representative volume should also contain no more than 3,000 acre-feet (3.714×10^9 liters) and meet any other requirements specified in 10 CFR 63.332(a)(1)–(3).

- The dimensions of the representative volume of ground water are calculated using one of the alternative methods specified in 10 CFR 63.332(b)(1)–(2).

4.2.1.4.3.5 References

None.