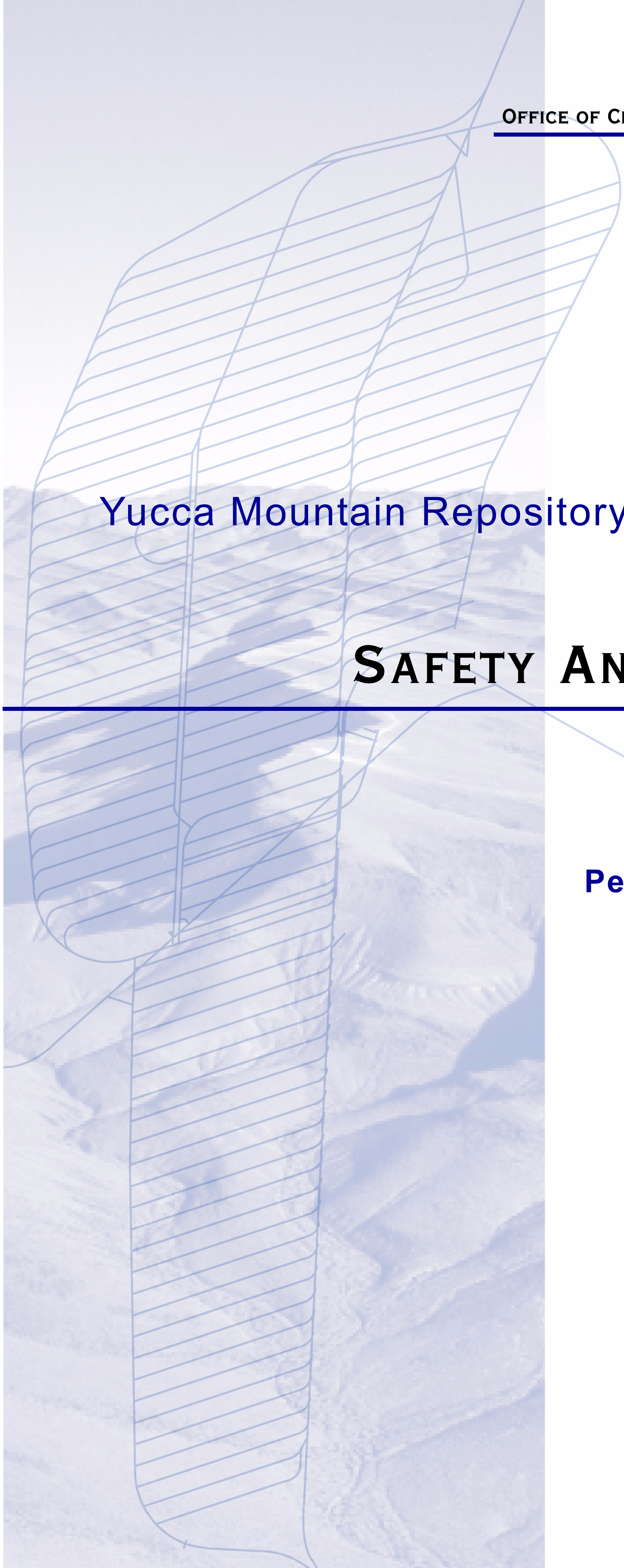

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Yucca Mountain Repository License Application

Safety Analysis Report

Chapter 4: Performance Confirmation Program

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CHAPTER 4 ACRONYMS

EBS	Engineered Barrier System
ECRB	Enhanced Characterization of the Repository Block
ESF	Exploratory Studies Facility
HLW	high-level radioactive waste
NRC	U.S. Nuclear Regulatory Commission
SNF	spent nuclear fuel

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4. PERFORMANCE CONFIRMATION PROGRAM

As required by 10 CFR 63.21(c)(17), this section provides information addressing requirements of 10 CFR 63.74(b) and 10 CFR 63, Subpart F. The Performance Confirmation Program will be conducted to meet the requirements of 10 CFR 63.131, 10 CFR 63.132, 10 CFR 63.133, and 10 CFR 63.134.

The scope of the Performance Confirmation Program does not include operational and administrative controls of processes, such as materials qualification, waste acceptance, or waste package handling. Section 5.6 addresses plans for the conduct of normal activities, including maintenance; surveillance; and routine periodic testing of structures, systems, and components and processes, based on the preclosure safety analysis and the postclosure performance assessment. Section 1.3.3 describes facilities related to the conduct of performance confirmation activities.

Additional information on the Performance Confirmation Program is available in *Performance Confirmation Plan* (SNL 2008a). The plan is published and available for U.S. Nuclear Regulatory Commission (NRC) inspection.

The information presented in this section addresses the applicable requirements contained in 10 CFR Part 63; the proposed changes to the regulation do not affect these requirements. This section also provides information that addresses specific regulatory acceptance criteria in Section 2.4.3 of NUREG-1804. The following table lists the information provided in this section, the corresponding regulatory requirements, and the applicable acceptance criteria from NUREG-1804.

SAR Section	Information Category	10 CFR Part 63 Reference	NUREG-1804 Reference
4	Performance Confirmation Program	63.21(c)(17) 63.44 63.71 63.72 63.73 63.111(e) 63.131 63.132 63.133 63.134	Section 2.2.1.3.4.3: Acceptance Criterion 5(4) Section 2.4.3: Acceptance Criterion 1 Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 4
4.1	Program Objectives and Overview	63.131(a)(1) 63.131(a)(2) 63.131(b) 63.131(c)	Section 2.4.3: Acceptance Criterion 1 Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 4(1) Acceptance Criterion 4(3)

SAR Section	Information Category	10 CFR Part 63 Reference	NUREG-1804 Reference
4.1.1	Program Implementation	63.131(d)(1) 63.131(d)(2) 63.131(d)(3) 63.132(a) 63.132(d) 63.44 63.71 63.72 63.73	Section 2.4.3: Acceptance Criterion 1(1) Acceptance Criterion 1(3) Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 4(1)
4.1.2	Program Documentation	63.44 63.71 63.72 63.73	Section 2.4.3: Acceptance Criterion 1(3) Acceptance Criterion 1(4) Acceptance Criterion 2(3)
4.1.3	Evaluation of Results and Reporting	63.131(d) 63.132(b) 63.132(d)	Section 2.4.3: Acceptance Criterion 1(1) Acceptance Criterion 1(4) Acceptance Criterion 2(3) Acceptance Criterion 3(1) Acceptance Criterion 3(2) Acceptance Criterion 3(4)
4.2	Performance Confirmation Program Activity Descriptions	63.131(a)(1) 63.131(a)(2)	Section 2.2.1.3.4.3: Acceptance Criterion 5(4) Section 2.4.3: Acceptance Criterion 1(1) Acceptance Criterion 1(2) Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 4
4.2.1	General Requirements	63.111(e) 63.131(a)(1) 63.131(a)(2) 63.132(a) 63.132(b) 63.132(e)	Section 2.2.1.3.4.3: Acceptance Criterion 5(4) Section 2.4.3: Acceptance Criterion 1(1) Acceptance Criterion 2(1) Acceptance Criterion 2(3)
4.2.2	Geotechnical and Design Monitoring and Testing	63.131(a)(1) 63.131(a)(2) 63.132(a) 63.132(b) 63.132(c) 63.132(d) 63.132(e)	Section 2.4.3: Acceptance Criterion 1(1) Acceptance Criterion 2
4.2.3	Design Testing Other than Waste Packages	63.133(a) 63.133(b) 63.133(c) 63.133(d)	Section 2.4.3: Acceptance Criterion 3
4.2.4	Monitoring and Testing of Waste Packages	63.134(a) 63.134(b) 63.134(c) 63.134(d)	Section 2.2.1.3.4.3: Acceptance Criterion 5(4) Section 2.4.3: Acceptance Criterion 4

This section is consistent with the information contained in the *Performance Confirmation Plan* (SNL 2008a). Section 4.1 provides an overview of the Performance Confirmation Program, including its objectives, administrative principles, and the implementation document hierarchy for the program. Section 4.2 describes the Performance Confirmation Program activities.

4.1 PROGRAM OBJECTIVES AND OVERVIEW
[NUREG-1804, Section 2.4.3: AC 1, AC 2, AC 3, AC 4(1), (3)]

The Performance Confirmation Program is responsive to the risk-informed, performance-based approach of 10 CFR 63, Subpart F. It is designed to confirm the adequacy of assumptions, data, and analyses that support the findings used to permit construction of the repository and waste emplacement. In essence, the Performance Confirmation Program evaluates information supporting compliance demonstrations of the postclosure performance objectives for individual protection (10 CFR 63.113(b)) and groundwater protection (10 CFR 63.113(c)), as well as consideration of preclosure aspects of repository performance (e.g., the ability to retrieve waste addressed in 10 CFR 63.111(e)).

Thus, there are two objectives for the Performance Confirmation Program. First, the program provides information, where practicable, to confirm that subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the expectations of the license application. This includes monitoring subsurface conditions and performing tests to confirm geotechnical and design assumptions that are the basis for compliance with the preclosure performance objective for retrievability. Second, the program provides information to confirm that the natural and engineered barriers are functioning as described in Chapter 2. This requires confirming selected information used to analyze compliance with the postclosure performance objectives for individual protection and the groundwater protection presented in Sections 2.4.2 and 2.4.4, respectively.

Performance Confirmation Plan (SNL 2008a) identifies 20 activities for performance confirmation. Some activities were selected as being most relevant to confirming preclosure and postclosure performance, based on current technical information and total system performance assessment results. Other activities were chosen to meet specific requirements described in 10 CFR 63, Subpart F. The decision analyses that resulted in selecting these activities will be periodically reassessed, based on updated technical information and total system performance assessment results, to assure the activities' continued relevance. New activities may be added, and currently planned activities may be curtailed or deleted as a result of these reassessments. The current conceptual descriptions of these activities will be supplemented by performance confirmation test plans that provide the rigor necessary to justify the activity, plan the details of its implementation, and establish condition limits for results that indicate significant differences from baseline information. Performance confirmation test plans have been written for seismic monitoring, precipitation monitoring, and construction effects monitoring. Other test plans will be prepared sequentially, and *Performance Confirmation Plan* (SNL 2008a) will be revised and updated as program development continues. The activities currently being planned for performance confirmation are described in Section 4.2.

The Performance Confirmation Program includes in situ monitoring and field and laboratory tests. The Performance Confirmation Program began during site characterization and will continue until permanent closure of the repository, in accordance with 10 CFR 63.131(b). Information from site characterization provided the basis for understanding the capability of natural and engineered barriers to delay flow and transport and for evaluating system performance. The understanding of barrier capabilities developed during site characterization therefore provides the basis for determination of activities that accomplish the purposes of the Performance Confirmation Program.

Examples of site characterization activities that transition to performance confirmation activities include geologic mapping in the Exploratory Studies Facility (ESF), hydrologic testing in the ESF and Enhanced Characterization of the Repository Block (ECRB) Cross-Drift, thermal testing in the ESF, and laboratory corrosion testing of waste package materials. The program confirms geotechnical and design parameters during repository construction and operation. A program for design testing related to borehole, shaft, and ramp seals; backfill; and drip shields will begin during early or developmental stages of construction. Waste package testing began during site characterization and will continue as long as practicable until permanent closure. The conditions related to the ability to retrieve waste will be monitored until completion of the Performance Confirmation Program and NRC authorization for permanent closure. Waste retrieval is discussed in Section 1.11.

10 CFR 63.51(a)(1) requires submission of an application to amend the license before permanent closure of the repository. This submission must include an update of the assessment of the performance of the repository for the period after permanent closure. This updated assessment must include any performance confirmation data collected under the program required by 10 CFR 63, Subpart F, and pertinent to compliance with the postclosure performance objectives in 10 CFR 63.113.

The phased nature of repository development allows for progressive development of performance confirmation approaches. Performance confirmation activity scheduling assumes a 100-year preclosure period, during which time performance confirmation activities will occur. A description of the process for performance confirmation test plan development has been developed (SNL 2008a).

4.1.1 Program Implementation

[NUREG-1804, Section 2.4.3: AC 1(1), (3), AC 2, AC 3, AC 4(1)]

The Performance Confirmation Program is administered by application of the principles listed below and is executed using the program documentation described in Section 4.1.2.

The Performance Confirmation Program is designed to:

- Provide baseline information and analysis of that information on parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, or operational activities.

- Monitor engineered systems and components intended to operate as barriers after permanent closure to ensure that they function, as assumed in the performance assessment.

- Monitor and analyze changes from baseline conditions that could affect repository design or performance.

- Compare measurements and observations with design bases and assumptions to identify significant differences that can be used by performance assessment to evaluate the significance of these differences to repository performance.

- Provide information for determining if modifications to the design or construction methods are warranted, consistent with design control processes to ensure proper safety evaluation and configuration management of necessary changes.

- Report significant differences between expected results and monitoring and testing information to the NRC, along with an evaluation of the effect of those differences on repository design or performance. Such evaluations can include recommended changes to construction methods, design, or performance analysis approaches.

- Confirm the bases relied upon for retrieval of waste.

- Provide information to update performance assessment prior to permanent closure.

Performance confirmation activities were selected using a risk-informed, performance-based methodology. The activity (test parameter and test method) selections judged as confirming repository performance were based on three criteria applied to a set of parameters identified by subject matter experts (SNL 2008a, Section 1.4.1):

- Sensitivity of barrier capability and system performance to the parameter
- Level of confidence in the current knowledge about the parameter
- Accuracy of information obtained by a particular test activity.

The decision analysis process was initiated by having subject matter experts identify key individual natural system and engineering parameters of interest to the definition of performance confirmation and associated methods of data acquisition. The subject matter experts identified over 300 combinations of parameters and data acquisition methods. These combinations, termed activities, were then evaluated by technical and subject matter experts for total system and subsystem (i.e., barrier) performance sensitivity to the parameter, confidence in the current representation of the parameter, and accuracy of the proposed activity in quantifying the parameter. Management value judgments were used to determine the relative importance of each technical criterion, and the resulting overall utility was calculated for each activity. Rough cost estimates were also produced for each activity (SNL 2008a, Section 1.4.1).

The decision analysis approach offered three key benefits in evaluating candidate activities. The approach (SNL 2008a, Section 1.4.1):

- Logically accounted for multiple objectives for the Performance Confirmation Program
- Incorporated information from personnel with different areas of expertise relevant to the selection of activities
- Provided a traceable and defensible logic for the performance confirmation activity selection.

The approach to activity selection for *Performance Confirmation Plan* (SNL 2008a) was conducted in several phases of evaluation and refinement by technical and management representatives. Twenty performance confirmation activities (Table 4-1) resulted from these reviews (SNL 2008a, Section 1.4.2).

During the selection process for Performance Confirmation Program activities, the approach was consistent with identification of monitoring and testing activities for systems, components, parameters, and effects that:

- Are reasonable and complete in the context of performance assessment
- Account for the effects of construction, waste emplacement operations, and interactions between natural and engineered systems included in the design bases
- Employ suitable methodologies to measure or monitor parameters of interest.

In 2005, assessments of the relationships between performance assessment and the 20 activities identified in *Performance Confirmation Plan* (SNL 2008a) were conducted for the purpose of evaluating any changes to the technical basis that occurred subsequent to the decision analysis process. The assessment activity included interviewing knowledgeable performance assessment staff with an understanding of the performance assessment model as implemented for the license application. The review concluded that no new performance confirmation activities were required, although the waste form testing was modified to address parameters in the igneous scenario.

This assessment was repeated in the 2007/2008 time frame, and demonstrated that the performance confirmation plan remains relevant to the license application bases, including *Total System Performance Assessment Model/Analysis for the License Application* (risk significance) (SNL 2008b) and *Postclosure Nuclear Safety Design Bases* (barrier capability) (SNL 2008c). The assessment affirms that the *Performance Confirmation Plan* (SNL 2008a) activities will support the technical basis for postclosure performance assessment of the natural and engineered barriers. No new performance confirmation activities have been identified based on this analysis. Comparison to the total system performance assessment sensitivity information provided in Appendix A[a] to the *Performance Confirmation Plan* addendum (SNL 2008a) shows that the most risk significant total system performance assessment parameters will be informed by performance confirmation activities. Based on the completeness review documented in Appendix A[a] to the *Performance Confirmation Plan* addendum (SNL 2008a), the planned performance confirmation activities as defined in the parent report are sufficient to address the features and characteristics that describe barrier capability. The *Performance Confirmation Plan* (SNL 2008a) may be revised in the future to reflect changes in the technical basis of the safety case. The performance confirmation test plans will contain the detailed identification and evaluation of parameters, bounds, and condition ranges, as demonstrated by the completed and available examples of those plans (BSC 2006; SNL 2007a; SNL 2007b).

Each of 20 activities in *Performance Confirmation Plan* (SNL 2008a) includes multiple parameters and monitoring options. The intent of the Performance Confirmation Program is to update periodically *Performance Confirmation Plan* (SNL 2008a) to ensure the information therein is consistent with the license application and reflects the most current understanding of the total system performance assessment. This philosophy is consistent with the concept of staged repository development, which updates the technical basis as knowledge increases. Development of the performance confirmation test plans will result in a more mature and realistic description of the activity appropriate for the more detailed planning stage of the activity, including determining the specific details for execution and appropriate duration of the testing. This will include specifying in performance confirmation test plans the specific tests and parameters that will meet the objectives of the activity. When final details in the individual performance confirmation test plans are determined, differences between the test plan as implemented versus the description in *Performance Confirmation Plan* (SNL 2008a) will be evaluated. The process for changes, tests, and experiments as specified in 10 CFR 63.44 will be applied to performance confirmation planning documents. A description of the change evaluation process responsive to the regulations as delineated in 10 CFR 63.44 is provided in Section 5.

4.1.2 Program Documentation
[NUREG-1804, Section 2.4.3: AC 1(3), (4), AC 2(3)]

Performance Confirmation Program implementation uses a hierarchical document structure that supports *Performance Confirmation Plan* (SNL 2008a) and guides its execution. *Performance Confirmation Plan* (SNL 2008a) scope and implementation will be periodically assessed to evaluate its continued relevance.

This approach ensures processes for (SNL 2008a, Section 5.2):

- Integrating the Performance Confirmation Program with performance assessment, design, and other testing programs
- Confirming the licensing basis that established the ability of the natural and engineered elements of the repository to meet the performance objectives
- Assessing the need for modifications to the Performance Confirmation Program scope to reflect updated performance assessment, sensitivity analyses, and ongoing science
- Analyzing performance confirmation testing and monitoring results in accordance with performance confirmation test plans

- Evaluating effects of performance confirmation results on design or performance assessments
- Complying with reporting records requirements for performance confirmation in accordance with 10 CFR 63.132(a) and (d).

Performance Confirmation Plan (SNL 2008a) identifies activities that are intended to satisfy regulatory requirements. Performance confirmation test plans include detailed planning and implementation for monitoring and testing activities. Figure 4-1 illustrates the planning and procedural documents hierarchy relevant to implementation of performance confirmation monitoring and testing. *Performance Confirmation Plan* (SNL 2008a), performance confirmation test plans, and detailed implementation documents will provide information on the aspects of the Performance Confirmation Program described herein including the following:

- Applicable procedures common to program administration, summarized in the plan, with detail provided in the performance confirmation test plans and supporting documents
- General reporting requirements for testing and monitoring results, summarized in Section 4.1.3
- Identification of testing activities provided in Section 4.2
- Testing and proposed monitoring methodology and techniques to be used, summarized in Section 4.2, with successive levels of detail provided in the plan, performance confirmation test plans, and supporting documentation
- Identification of candidate parameters for data to be obtained for each activity, as well as the risk-informed basis for selection of the parameters, summarized in Section 4.2, with successive levels of detail provided in the plan, performance confirmation test plans, and supporting documentation
- Estimated timing, overall duration, and frequency for each activity provided in Section 4.2.

The performance confirmation test plans, described below, will provide detailed information, as appropriate, including:

- A list of parameters to be measured
- A definition of each test parameter, including the basis for parameter selection
- Test methodology
- Equipment and instrumentation requirements, including reliability and replacement
- Planned tracers, fluids, and materials usage

- Environmental, safety, and health controls
- Identification and mitigation of hazards associated with the tests
- Software requirements
- Data acquisition
- Data management
- Sample control
- Calibration requirements
- Potential error or uncertainty sources, boundary tolerances or margins, including assumptions, as appropriate
- Acceptance criteria for results and data
- Defined ranges for the measured parameters (expected range and condition limits)
- Spatial and temporal frequency
- Baseline information
- Anticipated changes to be observed or measured during the period of the tests, including those that may be changed by site investigations, construction, and operations
- Identification of what constitutes trends or variations beyond the anticipated range during the monitoring or testing period
- Reporting and action processes and requirements.

Performance Confirmation Plan (SNL 2008a) describes development and review of test plans, which include detailed development of parameters and condition limits. As appropriate, site investigation test plans and technical work plans for activities conducted during and after site characterization will be revised and incorporated into performance confirmation test plans.

Conditions anticipated in the repository and the time frames involved require specific attention be given to instrumentation selection, maintenance and calibration scenarios, reliability and redundancy, and data collection. Appropriate accuracy or precision also needs to be part of test planning efforts and measurement or monitoring systems design. The complexity of some activities may warrant formal preparedness assessment reviews prior to startup (SNL 2008a, Section 5.2.2). Established procedures will be used to identify the need for such reviews and the process for conducting the review (SNL 2008a).

To implement activities described in performance confirmation test plans, detailed supporting documentation, shown in Figure 4-1, will be developed, in accordance with applicable procedures. Activity-specific implementing controls and requirements will be developed and documented. During operations, evaluation of effects on emplaced waste, test equipment exposure, and test equipment suitability for temperature and radiation levels will be addressed in the performance confirmation test plans (SNL 2008a, Section 5.2.3).

Field work packages provide a detailed and controlled mechanism for field activity planning that is typically not required for laboratory testing because offsite laboratory activities do not disturb the site, generally do not require environmental or other permits, and are controlled under facility safety and health plans, laboratory chemical hygiene plans, and laboratory-specific technical procedures (SNL 2008a, Section 5.2.3).

Technical procedures are used to describe the process steps for conducting the technical work. For field work, they are referenced in the field work packages and supplement the hazard analysis and hazard control process. Technical procedures are written for repetitive processes at the task level. Scientific notebooks, developed using existing procedures, complement technical procedures for investigation activities and detail the acquisition of data (SNL 2008a, Section 5.2.3).

Work orders and test work authorization for field test implementation are used to initiate field work activities. The work authorization process is currently defined in procedures for testing activities. This lowest level of planning for performance confirmation test activities consolidates task-specific work scope and applicable permits required to perform field work (SNL 2008a, Section 5.2.3).

Current work control and authorization processes will remain unchanged for the near term. However, it is anticipated that logistics related to site access and task-specific work control will evolve during the construction and operational phases (SNL 2008a, Section 5.2.3).

Records generated as a result of the test implementation will be handled, stored, submitted, and retained in accordance with applicable existing procedures. Data resulting from performance confirmation testing and monitoring activities will be managed in accordance with applicable records procedures (SNL 2008a, Section 5.2.3).

4.1.3 Evaluation of Results and Reporting

[NUREG-1804, Section 2.4.3: AC 1(1), (4), AC 2(3), AC 3(1), (2), (4)]

The Performance Confirmation Program is designed to collect information on subsurface conditions and natural and engineered barriers. Results from performance confirmation activities are used to confirm selected information or assumptions used in the performance assessment to demonstrate compliance with the postclosure performance objectives for individual and groundwater protection. Results from performance confirmation activities are also used to confirm design bases and assumptions, particularly as they relate to retrievability.

Reference data for selected design information and performance assessment input data and assumptions will be used to define the baseline values of parameters evaluated by the performance confirmation activities. Performance confirmation activity results will be analyzed and compared to expected ranges and limits developed from the corresponding baseline values. Significant differences between the activity results and the selected ranges and limits are assessed for their impact on baseline information. The details of this evaluation process depend on the data type and category collected in the activity, recognizing the uncertainties and conservatisms discussed in Section 2.4.2.3 (SNL 2008a, Section 4).

Baseline values are used to define objectives for performance confirmation investigations described in appropriate performance confirmation test plans. Sources for baseline values for selected parameters, test completion criteria, and variance criteria will be identified in performance confirmation test plans. For initial performance confirmation evaluations, the baseline data will be derived from analysis and model reports and performance assessment input parameters. For geotechnical and design parameters, the baseline values will be derived from reference design basis documentation.

Performance confirmation results that exceed condition limits established in the performance confirmation test plans indicating significant differences from baseline information used for compliance demonstrations are the basis for initiating procedures that lead to NRC notification. Following initial NRC notification, an evaluation report providing details about the comparison of performance confirmation results with construction, design, or performance assessment information is submitted to the NRC. If appropriate, the report will include an evaluation of the significant differences, description of proposed corrective actions, and an evaluation of the effects of proposed changes on the performance assessment. Recommended changes in construction, design, or performance assessment approaches resulting from the evaluation of the differences from baseline information will also be reported to the NRC. As appropriate, these evaluations and changes may require compliance with 10 CFR 63.44 or 10 CFR 63.73 (SNL 2008a, Section 4).

An integration review will be regularly conducted of performance confirmation information being collected, including an evaluation of the overall performance confirmation results. The review will evaluate whether the incremental performance confirmation results are interrelated, technically adequate and properly integrated. The review will ensure that barrier and system performance is assessed in the context of relevant performance confirmation information. Reporting to the NRC is planned to be consistent with overall reporting requirements for performance confirmation.

4.2 PERFORMANCE CONFIRMATION PROGRAM ACTIVITY DESCRIPTIONS

[NUREG-1804, Section 2.2.1.3.4.3: AC 5(4); Section 2.4.3: AC 1(1), (2), AC 2, AC 3, AC 4]

The repository Performance Confirmation Program is designed to conduct in situ monitoring, laboratory testing, and field testing, where practicable, to provide sufficient technical information to address 10 CFR 63.131 through 10 CFR 63.134 objectives described in Section 4.1. This section describes the proposed performance confirmation activities and is organized according to the major headings of 10 CFR 63, Subpart F, and NUREG-1804, Section 2.4.3.

Table 4-1 contains the proposed activities for the Performance Confirmation Program and provides a brief description of each. The listing denotes performance confirmation activities continued from site characterization or for which similar monitoring or testing was undertaken during site characterization. Table 4-1 also briefly describes the performance confirmation activities, candidate parameters, the purpose of the activity, and the relevant barrier or process for each activity.

Table 4-2 identifies the relationships between candidate performance confirmation activities and the requirements of 10 CFR 63, Subpart F.

Planning for currently identified candidate performance confirmation activities is ongoing; methods and approaches other than those discussed here may be employed. Monitoring and testing methodologies for performance confirmation activities conducted during site characterization, however, are well developed and in transition to address specific performance confirmation requirements. Construction period activities require refinement and finalization, while operational period activities are general conceptualizations. A schedule for the performance confirmation activities is provided in Figure 4-2.

Performance Confirmation Plan (Table 3-2 of *Performance Confirmation Plan* (SNL 2008a) provides specific references to the subsections) summarizes the results of an evaluation done on each activity and its potential for impact on repository performance in each of the subsections describing the 20 activities. The rationale for each activity is explained. It is not anticipated that any of the proposed activities will impact repository performance. Implementation details contained within the test plans will not affect the overall scope of the performance confirmation activity; however, deviations from the description provided in Section 4.2 will be evaluated according to 10 CFR 63.44.

4.2.1 General Requirements

[NUREG-1804, Section 2.2.1.3.4.3: AC 5(4); Section 2.4.3: AC 1(1), AC 2(1), (3)]

Performance Confirmation Program activities responsive to the general requirements of 10 CFR 63.131(a) include:

- **Subsurface Condition Monitoring and Testing**—Activities addressing 10 CFR 63.131(a)(1) (Table 4-2) provide for subsurface condition monitoring and testing to collect data that indicate, where practicable, if actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed. Activities principally designed to provide information relevant to these objectives are described in this section and in Section 4.2.2.

- **Natural and Engineered Barrier Monitoring and Testing**—Performance Confirmation Program activities directed at addressing requirements of 10 CFR 63.131(a)(2) (Table 4-2) provide for monitoring and testing to evaluate if natural and engineered barriers are functioning as intended and anticipated, as described in Sections 2.1 and 2.4.

For individual and groundwater protection, three barriers that limit radionuclide release and the rate of water or radionuclide movement are listed below and are discussed in Section 2.1.1:

- **Upper Natural Barrier**—Topography, soils, and the unsaturated zone of rock, including the emplacement drift horizon
- **Engineered Barrier System**—Drip shields, waste packages, cladding, waste forms, waste package pallets, invert, and emplacement drifts
- **Lower Natural Barrier**—The unsaturated zone rock below the drifts, as well as the saturated zone, consisting of saturated zone rock and alluvium.

Upper Natural Barrier—The natural features of Yucca Mountain include the rock strata above (part of the Upper Natural Barrier) and the rock below or hydrologically downstream of the repository (part of the Lower Natural Barrier). The rock strata above the repository consist of the surface soils and the unsaturated zone features, which together limit the rate and volume of water reaching the Engineered Barrier System (EBS). The performance of the rock strata above the repository will be evaluated by monitoring precipitation and seepage (Table 4-1) (SNL 2008a, Section 3.2).

Only a small fraction of the precipitation percolates through the rock to the repository horizon, and an even smaller fraction may be able to overcome the drift wall capillary effect to seep into the waste emplacement drift and contact the EBS. Seepage will be monitored at two types of locations: (1) in bulkheaded (i.e., unventilated) alcoves or boreholes at near-ambient temperature; and (2) in an unventilated thermally accelerated drift to detect thermally driven seepage into a heated and unventilated drift which represent conditions most typical of the postclosure repository (SNL 2008a, Section 3.2)

Mapping activities include documenting in situ conditions, including fractures, faults, and lithophysal characteristics (Table 4-1, subsurface mapping activity). Mechanical properties will be evaluated by measuring the deformation of underground openings during construction (SNL 2008a, Section 3.3.2.3). Planning for performing the Construction Effects Monitoring activities has been developed per a technical work plan (BSC 2006). Water samples will be obtained from the rock, and the water chemistry and age may be confirmed using chloride concentration and isotope chemistry (Table 4-1, subsurface water and rock testing activity). Seismicity monitoring will measure, evaluate, and report seismic activity. Evaluation of data includes comparison to the seismic information used to support the license application (SNL 2007a).

The mechanical, hydrologic, and chemical environment within the emplacement drifts affects the EBS performance. Some performance confirmation activities during repository construction are designed to evaluate selected assumptions and confirm data relevant to characterization of the in-drift environment (SNL 2008a, Section 3.2).

Host-rock near-field coupled processes monitoring will be accomplished by utilizing boreholes extended from an observation drift or alcoves toward a thermally accelerated drift. Near-field candidate parameters and observations include moisture content, fracture permeability, temperatures, thermal gradients, mechanical properties, deformation, and water chemistry (Table 4-1, thermally accelerated drift near-field monitoring activity) (SNL 2008a).

Confirmatory data about anticipated postclosure conditions in the repository will be obtained during the preclosure period using a thermally accelerated drift. Performance confirmation activities addressing the environment in a thermally accelerated drift relevant to characterization of the in-drift environment include several candidate parameters (Table 4-1, dust buildup monitoring and thermally accelerated drift in-drift environment monitoring activities) (SNL 2008a, Section 3.2).

Ramp, borehole, and shaft seal testing, required by 10 CFR 63.133(a) and (d), will also be conducted to evaluate their effectiveness (SNL 2008a, Table 3-2, and Section 3.3.3.1). This activity includes laboratory testing of the effectiveness of borehole seals followed by field-testing of the effectiveness of ramp and shaft seals.

Engineered Barrier System—The primary engineered features that isolate the waste from the accessible environment are the drip shield and waste package. See Sections 2.1, 2.3.4 and 2.3.6 for a description of these barriers, and the processes and events that impact these EBS components. The drip shield protects the waste package from seepage and rockfall and, to function as anticipated, must maintain integrity under expected postemplacement conditions. Accordingly, some activities directly monitor waste package and drip shield condition in a thermally accelerated drift. Periodic emplacement drift inspections are planned (Table 4-1, drift inspection activity). Results from monitoring drift shape changes in a thermally accelerated drift (Table 4-1, thermally accelerated drift thermal-mechanical monitoring activity) will be used to evaluate assumptions concerning thermally induced effects (SNL 2008a, Section 3.2).

The waste package in the environment of the natural system isolates radionuclides from the accessible environment. Performance confirmation activities will be undertaken to confirm the basis for estimating waste package performance. Waste package monitoring methods will be evaluated for the purpose of confirming waste package condition (Table 4-1, waste package monitoring activity). Additionally, visual inspections of the waste packages using remote monitoring techniques are possible (SNL 2008a, Section 3.2).

Performance confirmation activities evaluating corrosion processes continue current work for a range of potential waste package and drip shield material degradation modes. Performance confirmation includes evaluating samples exposed in the laboratory under a range of thermal and chemical environments, as well as samples exposed in a thermally accelerated drift in environments representative of long-term repository conditions (Table 4-1, corrosion testing and corrosion testing of thermally accelerated drift samples activities). Laboratory testing of waste forms is planned (Table 4-1, waste form testing activity) (SNL 2008a, Section 3.2).

To accomplish the performance confirmation objectives for some of these activities, thermally accelerated testing is conducted to emulate the postclosure environment and evaluate the response of the repository to expected thermal loads. The intent is to develop thermal environments in constructed emplacement drifts in which representative postclosure coupled thermal, hydrologic, mechanical, chemical, microbial, and radiological processes and effects can be monitored and/or observed (SNL 2008a, Section 3.3.1.9).

Activities planned in a thermally accelerated drift will monitor in-drift conditions, expose engineered barrier material samples to potential corrosion mechanisms in representative in situ environments, monitor drift degradation, and test near-field coupled processes. The thermally accelerated drift conceptual design includes a thermally accelerated drift at the repository horizon and an observation and instrumentation drift at a lower elevation (Section 1.3.3.1). Completion of the instrumentation and baseline measurements in the thermally accelerated drift (Section 1.3.3.1) will be accomplished early in the waste emplacement period. The thermally accelerated drift thermal-mechanical monitoring performance confirmation activity described in Section 4.2.2 will also be conducted in a thermally accelerated drift (SNL 2008a, Section 3.2).

Lower Natural Barrier—The tuff and alluvium below and downgradient from the repository represent unsaturated and saturated zone features that reduce the radionuclide movement rate (Sections 2.3.8 and 2.3.9). To confirm information used in the unsaturated zone transport models, transport and sorption properties will be tested in a seepage alcove or drift at ambient conditions (Table 4-1, unsaturated zone testing activity) (SNL 2008a, Section 3.2).

For the saturated zone, water levels and water chemistry will be monitored to evaluate assumptions and data about saturated zone flow and radionuclide transport (Table 4-1, saturated zone monitoring activity). Fault zones within the saturated zone influence flow rates and flow paths; therefore, testing fault zone hydrologic characteristics is included to evaluate assumptions about the effects of faults (Table 4-1, saturated zone fault testing activity). Data and assumptions about radionuclide transport in the saturated zone in the alluvium will be evaluated using tracer tests at an Alluvial Testing Complex (Table 4-1, saturated zone alluvium testing activity) (SNL 2008a, Section 3.2).

The following sections describe the individual Performance Confirmation Program test activities.

4.2.1.1 Precipitation Monitoring

This activity includes precipitation monitoring. Precipitation represents the predominant input of water into the Upper Natural Barrier system (Section 2.3.1.3.1.4). Monitoring precipitation began during site characterization and will continue until closure (SNL 2007b).

Purpose—The purpose of this activity is to confirm information used in conceptual and numerical models of the hydrologic conditions at Yucca Mountain. Data collected are used to confirm the adequacy of precipitation inputs in support of the process model abstraction described in Section 2.3.1. Precipitation quantity and spatial and temporal distribution were selected for potential monitoring parameters to confirm and extend the precipitation record for the site and for comparison with seepage observations (SNL 2008a, Section 3.3.1.1).

Performance Confirmation Test Plan for Precipitation Monitoring (SNL 2007b) describes an activity to monitor six stations used in the development of the infiltration model.

The Upper Natural Barrier contributes to waste isolation by limiting the amount of infiltrating water available to contact the EBS and by establishing the physical and chemical environment for the EBS. Infiltration into the unsaturated zone is limited through a combination of evaporation, transpiration, and runoff (Section 2.1.1).

The primary goal of the precipitation monitoring activity is to collect, analyze, and report on precipitation rates and quantities for the purpose of confirming precipitation input data for the infiltration model. These data are important because the infiltration model output is the input to the unsaturated zone flow model. The unsaturated zone flow model quantifies the moisture flux available for seepage and transport in the unsaturated zone at Yucca Mountain (SNL 2007b).

Description of Current Understanding—The climate conditions of both present-day and future climates are characterized by mean annual precipitation rates ranging from approximately 190 to 300 mm/yr. Mean net infiltration rates range from less than 15 to about 30 mm/yr, even in cooler, wetter future climates (Section 2.3.1, Tables 2.3.1-2, 2.3.1-3, and 2.3.1-4). Precipitation monitored during the construction or operations period is forecast to continue present-day climate ranges (SNL 2008a, Section 3.3.1.1).

The baseline data for this activity is derived from the analysis supporting infiltration modeling for the license application (SNL 2008d).

Methodology—Precipitation monitoring will continue until repository closure (SNL 2008a, Section 3.3.1.1). Initially, it uses six of the existing monitoring stations described in Section 1.1.3. Because the precipitation monitoring activities will be conducted for an extended period, updates to the equipment, sampling activities, and methodologies are expected and will possibly be modified in the performance confirmation test plans.

4.2.1.2 Seepage Monitoring

This activity includes seepage monitoring and laboratory analyses of samples collected in the subsurface and may include monitoring of barometric pressure, temperature, and humidity of ventilation air. Seepage represents the fraction of water flow from the Upper Natural Barrier that can enter the drift to contact the EBS. The seepage water chemistry influences possible engineered component degradation induced through aqueous corrosion. Seepage water also provides the primary medium for radionuclide release and transport from the EBS. General seepage monitoring will be conducted in nonemplacement drifts, in conjunction with drift inspections (Section 4.2.1.8). Seepage monitoring includes specific monitoring in unventilated alcoves on the intake side of the repository and in a thermally accelerated drift. Seepage monitoring in sealed ambient condition alcoves and in the ECRB Cross-Drift began during site characterization and will continue to be expanded to new areas through closure (SNL 2008a, Section 3.3.1.2).

Purpose—The purpose of this activity is to evaluate results from the seepage model and to evaluate unsaturated zone flow in the rock strata above the repository discussed in Section 2.3.3. Seepage monitoring results are used to evaluate: (1) the spatial and temporal distribution of seepage in the drifts and, if possible, to obtain samples of the seepage water for chemical analysis; and (2) the thermal loading effect on the spatial and temporal extent of seepage and on water chemistry (SNL 2008a, Section 3.3.1.2).

Description of Current Understanding—The rock strata of the Upper Natural Barrier limits water movement through the unsaturated zone, as described in Section 2.1.2.1. Water flow in the fractured welded tuffs above the repository occurs primarily in fractures. In contrast, the Paintbrush nonwelded hydrogeologic unit between the fractured welded Tiva Canyon and

Topopah Spring welded tuffs is dominated by matrix flow. Matrix flow in the Paintbrush nonwelded unit tends to attenuate, or dampen, the amplitude of pulses in fracture-dominated flow in the Topopah Spring welded unit. This damping effect reduces the percolation rate variability at depth (Section 2.1.2.1) (SNL 2008a, Section 3.3.1.2).

Underground openings in unsaturated rock divert water around them because of capillary forces, as described in Section 2.1.2.1. As a result, much of the water that percolates downward through the unsaturated zone does not seep into the drifts. However, the water potential in the rock can overcome the effect, allowing water to enter the drifts and evaporate, flow as a film down the wall, or drip into the drift. For the purposes of these analyses, only dripping water is considered "seepage." Repository thermal loads may result in zones of boiling, condensation, and drainage that are expected to influence the seepage distribution and water chemistry (SNL 2008a, Section 3.3.1.2).

To quantify and model flow in the unsaturated zone, testing was conducted during site characterization in the ESF, in the ECRB Cross-Drift, and at the Busted Butte Test Facility (Section 2.3.2.1) (SNL 2008a, Section 3.3.1.2).

Models and analogue geologic data indicate that only a fraction of drip shield locations will be contacted by seepage water in current climatic conditions (Section 2.3.3 and Figure 2.3.3-48). Also, the repository design utilizes the heat generated by emplaced waste to further limit the amount of water available to seep into the emplacement drifts. Under expected conditions, no liquid water is available to flow into emplacement drifts for several hundred years following closure (Section 2.1.1.1).

If seepage is observed under ambient conditions, it may provide information to confirm assumptions about the spatial and temporal distribution of seepage and the chemistry of seepage water in the repository. Although seepage is not anticipated following waste emplacement, based on seepage modeling results, monitoring will take place in a thermally accelerated drift to help support the results of these analyses.

The baseline data for this activity will be synthesized from performance assessment results, as well as from information in analysis and model reports (SNL 2008a, Section 3.3.1.2).

Methodology—Seepage monitoring and sampling will include monitoring occurrences and quantities, as well as conducting laboratory analyses of seepage fluids. This monitoring will be conducted at appropriate locations in the subsurface, and specific tests will be conducted in unventilated alcoves or boreholes and in a thermally accelerated test drift. General monitoring for seepage will occur throughout repository construction and operations (Section 4.2.1.8), and specific tests will be conducted as early as practicable (SNL 2008a, Section 3.3.1.2).

For specific test activities, remote video systems will be used to identify seepage in unventilated alcoves and a thermally accelerated drift. Considering the occurrence of observable seepage, if it occurs, humidity and temperature monitoring of the exit air at a location with suitable access and utilities in a thermally accelerated drift could be used to detect marked humidity or temperature changes (e.g., spikes or trends) (SNL 2008a, Section 3.3.1.2).

The technology to provide a remote means to detect seepage in bulkheaded alcoves is available. However, the high-temperature and high-radiation environments representative of postemplacement conditions in a thermally accelerated drift require development of specific technology applications (SNL 2008a, Sections 3.2 and 3.3.1.8).

4.2.1.3 Subsurface Water and Rock Testing

This activity includes sampling and laboratory analysis of water, rock, and fracture-filling materials from various locations in the subsurface. This activity may include laboratory analysis of isotopes and other ions to be specified in the performance confirmation test plan, as determined from samples from selected locations in the underground facility. The results provide the rock and water chemistry of the Upper Natural Barrier in the immediate vicinity of the repository openings. Rock, fracture-filling material, and water sample collection and data analysis began during site characterization and will continue throughout repository construction (SNL 2008a, Section 3.3.1.3).

Purpose—The purpose of this activity is to evaluate whether the Upper Natural Barrier operates as expected and to verify assumptions for fast paths used in unsaturated zone models. Results from sampling and laboratory analysis of water, rock, and fracture-filling materials are used to confirm the actual subsurface conditions encountered. The geochemistry sampling and analysis are used to evaluate (SNL 2008a, Section 3.3.1.3):

- The potential percolation flux through the repository level
- Whether the fast pathway parameters (environmental data) used in the unsaturated zone flow analysis sufficiently represent subsurface conditions
- The effects of water–rock interaction on the isotopic systems at the bulk-rock scale
- The percolation history of flow through the unsaturated zone using the ages and isotopic composition of low-temperature fracture minerals.

Rock-matrix water sampling supplements seepage quantity and quality monitoring (Section 4.2.1.2). Seepage is not expected to occur over large areas of the repository. Results from this activity are used to confirm the chloride concentration and isotopic information used in conceptual and numerical models to describe the hydrologic conditions for flow in the unsaturated zone described in Section 2.3.2.3 (SNL 2008a, Section 3.3.1.3).

Description of Current Understanding—Sampling and laboratory analysis of water, rock, and fracture-filling materials began during site characterization. Chloride concentration data from analysis of ESF and ECRB Cross-Drift samples indicate spatial variability of surface infiltration and percolation flux. Isotopic geochemistry data are used to develop a conceptual understanding of flow and transport in the unsaturated zone (SNL 2008a, Section 3.3.1.3).

The baseline data for this activity will be identified in a performance confirmation test plan, based on scientific analysis from performance assessment input data and analysis and model report information (SNL 2008a, Section 3.3.1.3).

Methodology—The pore-water, rock, and fracture coating isotopic geochemistry samples will be collected at appropriate subsurface locations within the repository. Samples will be obtained from boreholes using drilling and handling techniques that maintain sample integrity. Water extracted from rock cores will be analyzed by ion chromatography for a comprehensive suite of dissolved ions. The core will be used for bulk rock analyses of uranium and strontium isotopes. In addition to the core samples, fracture coating samples will be taken at appropriate locations in the drifts, such as faults and fractures where a high concentration of fracture coatings suggests a high percolation flux, and analyzed for isotope geochemistry (SNL 2008a, Section 3.3.1.3).

4.2.1.4 Unsaturated Zone Testing

This activity includes testing of transport properties and field sorptive properties of the Topopah Spring Tuff crystal-poor member in an ambient seepage alcove or a drift with no waste packages emplaced. Unsaturated zone testing confirms information on transport properties and the rock and water chemistry near the repository openings. This activity began during site characterization and will continue during construction and emplacement (SNL 2008a, Section 3.3.1.4).

Purpose—The purpose of this activity is to confirm that information for license application on sorption coefficients in the host rock used to evaluate transport properties in the unsaturated welded, fractured rock below the repository are within established limits (Section 2.3.8). The performance confirmation activities associated with the transport and sorptive properties of the Topopah Spring Tuff include testing to evaluate the information used in conceptual and numerical models to describe flow and transport in the unsaturated zone at Yucca Mountain described in Sections 2.3.2 and 2.3.8 (SNL 2008a, Section 3.3.1.4).

The sorption coefficient K_d is used to incorporate sorption into transport models (Section 2.3.8.2). This activity will provide information to confirm K_d value approximations using field test results. These results will be compared to laboratory batch tests and to the K_d values used in the performance assessment models to evaluate the appropriateness of the K_d values used in transport models (SNL 2008a, Section 3.3.1.4).

Description of Current Understanding—The repository horizon is underlain by approximately 215 to 365 m of unsaturated volcanic rock exhibiting varying degrees of welding, which affects both the fracture density and matrix conductivity. Densely welded tuffs are brittle and typically develop interconnected fractures, which may allow water to divert around areas of lower conductivity, whereas nonwelded tuffs exhibit low fracture density and higher matrix conductivity (SNL 2008a, Section 3.3.1.4).

The natural barrier below the repository (Lower Natural Barrier) limits and delays radionuclide movement to the accessible environment through a variety of natural processes. In the unsaturated zone, these processes include low water flow rates, matrix diffusion that mechanically traps radionuclides in the rock, and chemical adsorption of radionuclides onto mineral surfaces.

Transport of radionuclides through the unsaturated zone mainly occurs in fractures within the welded units (BSC 2004, Section 7.9.2.1). Parameters in the nonwelded units (where matrix conductivity predominates) have been characterized during site characterization (BSC 2004, Section 7.2). Fractures are difficult to sample and test in the laboratory, so in situ testing in alcoves may be used to assess heterogeneous effects and confirm parameter values used in performance assessment (SNL 2008a, Section 3.3.1.4). The relationship to the performance assessment will be described in a performance confirmation test plan.

Sorption is a general term that describes a combination of chemical interactions between the dissolved radionuclides and the surrounding rock. The sorption capability of the Lower Natural Barrier is radionuclide specific. For the short-lived radionuclides that comprise most of the repository inventory at emplacement (e.g., cesium, strontium), radioactive decay reduces the activity and amount of the nuclides to negligible levels long before they are transported to the accessible environment. For the long-lived, moderately to strongly sorbing radionuclides (e.g., plutonium, neptunium), the Lower Natural Barrier retards transport by thousands of years and reduces their activity at the accessible environment. For the nonsorbing or mobile radionuclides (primarily technetium and iodine), the tuff and alluvium in the Lower Natural Barrier disperses and retards transport for hundreds to thousands of years (Section 2.1) (SNL 2008a, Section 3.3.1.4).

The baseline data for this activity will be synthesized from performance assessment results, as well as from analysis and model reports (SNL 2008a, Section 3.3.1.4).

Methodology—This activity includes in situ experiments, field mapping, field testing, and laboratory analysis of samples collected from the field tests. The transport and sorption testing will be conducted in two or more seepage monitoring alcoves located within the repository. Testing will begin during the construction phase and continue to the early stages of the emplacement period (SNL 2008a, Section 3.3.1.4).

The repository will be constructed in the crystal-poor middle nonlithophysal and the crystal-poor lower lithophysal units. The plan is to execute at least one test in each of these units. Fracture-mapping data will be used to select test locations within the seepage alcoves, and to ensure that the selected test locations are representative. The proposed methods include single borehole and cross-hole air-injection and water release testing. After the fracture flow system has been quantified and flow between the boreholes identified, the fracture system will be locally saturated and liquid tracers released in the upper boreholes. Tracers will be selected to represent both highly sorptive and poorly sorptive radionuclides. Estimates of the K_d values are expected to be derived from test results and compared with laboratory results obtained using the same rock types and tracers consistent with the bases used in Section 2.3.8 (SNL 2008a, Section 3.3.1.4).

4.2.1.5 Saturated Zone Monitoring

This activity includes monitoring, sampling, and analyzing saturated zone water from Nye County and site wells for water levels, Eh, pH, and radionuclide concentrations. Saturated zone monitoring began during site characterization and will continue through construction and the emplacement period until permanent closure (SNL 2008a, Section 3.3.1.5).

Purpose—The purpose of this activity is to evaluate hydrologic and chemical parameters used with the saturated zone flow model. Saturated zone testing includes monitoring groundwater in wells upgradient and downgradient from the repository. It also includes associated laboratory testing for groundwater chemistry and radionuclide concentrations. This activity will evaluate the groundwater chemical characteristics, the absence of repository radionuclides in downgradient wells, and the arrival of radionuclides from upgradient sources, such as nuclear testing (SNL 2008a, Section 3.3.1.5).

This activity indirectly confirms the integrity of the EBS and the transport properties in the unsaturated zone below the repository. The Lower Natural Barrier saturated zone feature includes the volcanic rock and alluvium in the saturated zone below the water table that delays the movement of radionuclides (Section 2.1.1.3).

Description of Current Understanding—Section 2.3.9.2 describes the site-scale groundwater flow system in the context of saturated zone flow and transport. This activity includes monitoring, sampling, and analyzing saturated zone water from existing wells. Annual or biennial sampling may be used. Shallower wells in the alluvium may require quarterly sampling initially until the seasonal or other short-term variations are understood (SNL 2008a, Section 3.3.1.5).

Due to the length of the period of groundwater transport and the unlikely failure of the EBS during the preclosure period, the detection of radionuclides from the repository is not expected during the monitoring period. However, changes of parameters such as water levels, Eh, and pH may be used to evaluate changes in the geohydrologic system (SNL 2008a, Section 3.3.1.5).

The baseline information for groundwater chemistry and water levels in the alluvium for this activity will be synthesized from TSPA results as well as from information obtained from analysis and modeling reports.

Methodology—Groundwater level monitoring and water sampling of Nye County and site wells for analysis of the parameters Eh and pH are performed periodically and will continue until repository closure. Current field instrumentation is available and will be used for measuring water levels, Eh, and pH. Delivery of groundwater samples to a laboratory would be required for radionuclide concentrations analysis.

4.2.1.6 Saturated Zone Fault Hydrology Testing

This activity includes fault zone hydrologic characteristics testing in saturated fractured and nonwelded tuffs to evaluate fault zone characteristics used in the saturated zone flow and transport models. This activity will be initiated during construction. Testing would include separate phases of pumping, tracer injection, and recovery at multiple locations; phases are expected to be 1 to 3 years in duration (SNL 2008a, Section 3.3.1.6).

Purpose—The purpose of this activity is to evaluate fault parameter assumptions in the saturated zone flow and transport models. The results will be used to evaluate fault zone hydraulic conductivity (permeability), porosity, dispersivity, and anisotropy in saturated fractured and nonwelded tuff downstream from the repository. This activity confirms the fault zone characterization as a part of the basis for evaluating anticipated performance in the saturated zone of the Lower Natural Barrier used in the saturated zone flow and transport models that support performance assessment (Section 2.3.9).

Description of Current Understanding—Section 1.1.4 describes the site groundwater hydrology, and Section 2.3.9.2 describes the site-scale groundwater flow system in the context of saturated zone flow and transport, including variations in structure and permeability in the site vicinity. Faults may act as barriers to flow or preferential pathways, and both conditions have been identified near the site.

This portion of the saturated zone barrier is complicated by the faulting and tilting of the volcanic rocks. It is represented in an equivalent porous medium model in terms of two weakly coupled aquifers: an upper volcanic aquifer associated with the Topopah Spring Tuff units and a lower volcanic aquifer associated with the Prow Pass, Bullfrog, and Tram Tuff units (Section 2.1.2.3). Tests that address fault zone hydrologic characteristics are anticipated to confirm assumptions about flow paths and rates.

The hydraulic and transport characteristics of the tuff aquifers along the projected transport path of groundwater from Yucca Mountain were investigated by single- and cross-hole hydraulic testing. This testing was done at the C-Wells complex in three boreholes drilled with test intervals in the Crater Flat Group. In addition, testing included a large-scale, longer-term pump test (Section 2.3.9.2).

Testing activities similar to this performance confirmation activity have been conducted at the C-Wells testing complex and in the interpretation of boundary conditions in other well tests. Baseline data for this activity will be synthesized from performance assessment assumptions, as well as from published results from analogue sites in fractured and faulted rocks (SNL 2008a, Section 3.3.1.6).

Methodology—This relatively short-duration testing activity includes monitoring of water levels during ambient and stress conditions, tracer injection, field sample collection (including limited onsite or in situ analysis), and offsite laboratory analysis. Testing may include single- and cross-hole pumping and tracer tests using boreholes with spacing (both in plan view and with depth), depending on predictive modeling and test objectives. Fault testing details will be provided in the performance confirmation test plan.

One proposed methodology includes a new test site located such that three new boreholes would be drilled in and across a major block-bounding fault system (e.g., the Solitario Canyon Fault system), with packers installed to allow three-dimensional hydraulic and tracer testing. At another site downgradient from the repository, similar testing is planned. At this location, the testing may concentrate on the Crater Flat Group but might also allow testing of the deeper Tertiary tuff or the shallower Paintbrush Group, depending on the final placement and configuration of the wells (SNL 2008a, Section 3.3.1.6).

The boreholes could both straddle and penetrate faults. Test intervals would be isolated in each borehole, allowing them to function as point sources. The use of three boreholes with appropriately placed test intervals allows cross-hole hydraulic and tracer testing in both the horizontal and vertical planes. Boreholes that penetrate faults would allow the conduct of tests in the hanging wall, the fault zone, and the footwall. Single- and cross-hole hydraulic testing could quantify the fault zone hydraulic conductivity, porosity, and anisotropy. Cross-hole tracer testing could be used to evaluate dispersivity and sorption characteristics (SNL 2008a, Section 3.3.1.6).

4.2.1.7 Saturated Zone Alluvium Testing

This activity includes tracer tests using boreholes at the Alluvial Testing Complex to confirm transport properties of the alluvium along the potential flow path south of Yucca Mountain. This activity began during site characterization and can be resumed and continued at any time. Testing is anticipated to take from 1 to 3 years (SNL 2008a, Section 3.3.1.7).

Purpose—The purpose of this activity is to confirm inputs and assumptions for the saturated zone flow and transport model. It includes testing and monitoring of the alluvium to evaluate the assumptions and results of conceptual and numerical models describing saturated zone hydrologic conditions in the alluvium south of the site (SNL 2008a, Section 3.3.1.7). These models are described in Section 2.3.9.

Below the repository, the Lower Natural Barrier limits and delays radionuclide movement to the accessible environment through a variety of natural processes. The saturated portion of the Lower Natural Barrier includes the saturated alluvium. Saturated zone processes that limit radionuclide movement include low groundwater flow rates, matrix diffusion, sorption, and filtration of colloids that could potentially transport radionuclides (Section 2.1.1.3).

Description of Current Understanding—Hydraulic testing of the alluvium has been performed at the Alluvial Testing Complex, south of Yucca Mountain. The Alluvial Testing Complex is approximately located at the boundary of the accessible environment, as specified in 10 CFR 63.302. The location of the Alluvial Testing Complex is approximately 18 km from Yucca Mountain; testing was performed in the alluvium aquifer (SNL 2007c). Testing yielded data used to develop models of groundwater-specific discharge (Section 2.3.9.2). Data from testing at this location are used to support validation of the saturated zone flow model in the specific discharge estimates, which were based on input from an expert elicitation panel and the results from hydraulic and tracer testing in tuff. Uncertainties in the specific discharge estimates are used in the flow and transport model abstractions, described in Section 2.3.9.2.

The conceptual model for transport in the alluvial sediments is that of a porous continuum. The effective porosity of the alluvium is greater than the fracture porosity of the tuffs. Consequently, pore velocities in the alluvium are smaller than those in the fractures of the volcanic aquifers, and radionuclide movement is slow because of the low water velocity. In addition, sorption onto minerals in the alluvium results in retardation of the radionuclide movement relative to the water movement in these sediments (SNL 2008a, Section 3.3.1.7).

The baseline data for groundwater chemistry and water levels in the alluvium for this activity will be synthesized from performance assessment results, as well as from analysis and model reports (SNL 2008a, Section 3.3.1.7).

Methodology—This short-duration testing activity includes monitoring of water levels during ambient and stress conditions, tracer injection, field sample collection (including limited onsite or in situ analysis), and offsite laboratory analysis. Boreholes will be used to conduct single- and cross-hole hydraulic and tracer tests throughout the saturated thickness of the alluvium in isolated intervals in the boreholes. Prior to conducting tracer tests, selected intervals will be pumped to quantify vertical leakage in the well to determine the analysis methods necessary for the hydraulic tests and to identify intervals for cross-hole tracer tests (SNL 2008a, Section 3.3.1.7).

Comparison of field transport behavior of a tracer with its laboratory transport behavior is important to evaluate the use of laboratory-derived sorption parameters in field-scale radionuclide transport analyses. Additional laboratory batch and column sorption tests will be conducted to compare the sorption values of tracers with the sorption values of radionuclides. Laboratory tests will be used to confirm information used in modeling saturated zone flow and transport or sorption in the alluvium (SNL 2008a, Section 3.3.1.7).

4.2.1.8 Drift Inspection

Periodic Inspection of Drifts and Mains—This activity includes regular nonemplacement drift inspections, along with periodic inspection of selected emplacement drifts and a thermally accelerated drift. Inspection may include observation of temperature and humidity, and observations that might include rockfall, sagging ground support, significant changes in EBS component positions, invert degradation, changes to drift stability based on or caused by seismic movement, and occurrences of seepage, if it occurs. This is an activity that focuses on repository operations areas and confirms preservation of the option to retrieve spent nuclear fuel (SNF) and high-level radioactive waste (HLW). Similar inspection activities were conducted during site characterization in the ESF, alcoves, and ECRB Cross-Drift. Drift inspections, including those to confirm preservation of the retrieval option, will begin during operations and will continue through closure (SNL 2008a, Section 3.3.1.8).

Purpose—The purpose of this activity is to evaluate drift stability assumptions, both within emplacement drifts and nonemplacement drifts, and rockfall size. The activity also supports confirmation of retrievability preservation. This activity is expected to confirm that EBS components will endure, and also confirm that the design preserves the option to retrieve waste by direct observation (SNL 2008a, Section 3.3.1.8).

Description of Current Understanding—Drift inspection activities were conducted during site characterization in the ESF, alcoves, and ECRB Cross-Drift. This activity benefits from the experience in remote visual observations made in the Drift Scale Test using cameras. Although not the configuration that will be used in the emplacement drifts, the Drift Scale Test employed a thermally insulated remote video unit that traveled to the back of the 50-m-long drift on a gantry and provided video, still, and infrared images of the drift. These images were used to assess drift stability conditions, to look for evidence of seepage, and to observe general simulated waste package and test component conditions (SNL 2008a, Section 3.3.1.8).

Baseline information for this activity will be developed from analysis and model reports (SNL 2008a, Section 3.3.1.8).

Methodology—Regular inspections of nonemplacement drifts may include direct observation of temperature, humidity, liquid seepage, rockfall, sagging ground support, and drift continuity. Periodic inspection of selected emplacement drifts and a thermally accelerated drift may involve similar observations, including changes in waste package position and changes to rail alignment (SNL 2008a, Section 3.3.1.8).

The technology could consist of a remotely operated vehicle equipped with cameras and sensing devices. In addition, sensor devices to measure temperature, measure other environmental conditions, and make observations of potential drift seepage could be included on a remote monitoring mechanism (SNL 2008a, Section 3.3.1.8).

Inspections involve monitoring drift stability and the status of the rail or other systems. Preservation of the retrievability option within the emplacement drifts may depend on the functionality of these systems. The drift opening will be monitored to verify that rockfall or convergence of the drift back, ribs, and invert have not adversely affected the clearance envelope required for package removal (SNL 2008a, Section 3.3.1.8).

The performance confirmation test plan will identify a scheduled inspection of selected emplacement drifts to be performed. However, following large seismic events, monitoring emphasis will be directed, as appropriate, at areas with geologic features identified during emplacement drift mapping to evaluate effects on engineered systems (SNL 2008a, Section 3.3.1.8). Observation of the condition of the underground openings will be made at regular intervals and following significant seismic events, should they occur during the preclosure period. These observations will be assessed in concert with other performance confirmation activities such as seismicity monitoring and subsurface mapping to determine opening stability. Walkdowns will be performed following seismic events that are considered significant, as determined by estimated peak ground velocity at the repository location. The peak ground velocity trigger value for initiating a walkdown are provided by limits specified in *Seismic Monitoring Test Plan* (SNL 2007a).

Planning for this activity is conceptual, and other methods and approaches may be employed. While the technology to provide a remote means to inspect selected emplacement drifts is available, the high-temperature and high-radiation environments representative of postemplacement conditions in emplacement drifts will require development of specific technology applications (SNL 2008a, Sections 3.2 and 3.3.1.8).

4.2.1.9 Thermally Accelerated Drift Near-Field Monitoring

This activity includes monitoring of near-field coupled processes (thermal-hydrologic-mechanical-chemical) properties and parameters associated with the thermally accelerated drift. This activity will be initiated during operations and will continue until closure (SNL 2008a, Section 3.3.1.9).

Purpose—The purpose of this activity is to evaluate coupled process results from the thermal-hydrologic-mechanical-chemical model relevant to the Upper Natural Barrier and Lower Natural Barrier. This activity monitors the near-field properties in a surrogate environment for postclosure conditions. Measurements will be made of conditions and changes attendant to thermal loading in the fractured, unsaturated rock. Ongoing evaluations of the measurement data of these coupled processes that affect water chemistry, porosity, and matrix and fracture permeability are intended to assess the modeled repository performance bases pertaining to drift seepage (SNL 2008a, Section 3.3.1.9).

Description of Current Understanding—Evolution of the near-field environment involves coupled thermal-hydrologic-mechanical-chemical processes. Water and gas compositions will be influenced by chemical reactions within the unsaturated fractured rock. Local changes in water and gas chemistry may result from interactions with engineered materials or corrosion products or both. These processes also include evaporation, mineral dissolution and precipitation, and aqueous and gaseous-phase transport and chemical reactions (SNL 2008a, Section 3.3.1.9).

The Large Block Test, the Single Heater Test, and the Drift Scale Test (Section 2.3.3.3.2) were conducted to examine the impact of repository heat on the hydrologic, chemical, and mechanical conditions. The Single Heater Test and the Drift Scale Test were conducted in the ESF, and the Large Block Test was conducted at Fran Ridge (SNL 2008a, Section 3.3.1.9).

The near-field environment is the rock mass and conditions immediately surrounding the drifts that experience heating or excavation-related changes in rock properties. Interactions between the natural system and heat generated by radioactive wastes could cause both permanent and transient property changes within a region that extends into the rock mass (SNL 2008a, Section 3.3.1.9).

An established baseline for this activity is not yet available, especially as it relates to conditions created by actual waste packages or to conditions in units other than the crystal-poor middle nonlithophysal tuff. Monitoring of thermally induced rock property changes similar to these has been conducted during site characterization in the ESF and ECRB Cross-Drift. This specific performance confirmation activity will not begin until the thermally accelerated drift is constructed and waste packages are emplaced (SNL 2008a, Section 3.3.1.9).

Near-field monitoring will collect data that will be compared with ranges used in numerical models and acquired from thermal results reports. This comparison allows evaluation of the consistency of the ranges for the parameters measured in situ and the data used for the conceptual and numerical models relevant to seepage and coupled processes (SNL 2008a, Section 3.3.1.9).

Methodology—Monitoring will be accomplished using boreholes drilled into the near-field rock surrounding the thermally accelerated drift from an adjacent observation drift. The test and observation drifts are described in Sections 1.3.3.1.6 and 1.3.3.1.7. Arrays of boreholes will be designed for specific monitoring measurements to be performed. Core will be collected from boreholes to confirm initial in situ rock moisture content and chemistry. Appropriate geophysical equipment will be deployed, based on experience and data-quality objectives. Sample collection and monitoring the near-field environment will be identified in the performance confirmation test plan, as appropriate (SNL 2008a, Section 3.3.1.9).

4.2.1.10 Dust Buildup Monitoring

This activity for monitoring and laboratory testing of the quantity and composition of dust on engineered surfaces provides information to confirm certain aspects of the environment that EBS components will endure. This activity of dust collection and evaluation began during site characterization and will continue during operations. Dust will be collected in the thermally accelerated drift and other selected locations after startup of the ventilation system. The locations will be sampled periodically. Other methods and approaches may be employed (SNL 2008a, Section 3.3.1.10).

Purpose—The purpose of this activity is to evaluate dust buildup and potential chemical effects on EBS features. It evaluates the expected emplacement environment and the representativeness of drip shield and waste package testing conditions. Dust accumulation on the surface of the drip shield and on the waste package outer barrier has a role in determining the chemical characteristics of the aqueous environment for these two components. Evaluating the range in chemistry of water contacting the engineered barriers is relevant to determining engineered material corrosion rates (SNL 2008a, Section 3.3.1.10).

Description of Current Understanding—During the repository operations period, the ventilation system distributes particulate matter, some of which may settle on waste package surfaces. Also, after the repository is closed, fine debris from the host rock settles on exterior surfaces. This debris is expected to originate mainly from rock dust that contains the various tuff mineral components, salts, and precipitated chemical species (SNL 2008a, Section 3.3.1.10).

Much of the dust material comes from rock crushing during tunnel construction. Salts in the dust may have deliquescent properties. The deliquescent properties of the salts decrease the relative humidity at which corrosion reactions can occur. Thus, the composition of the dust material that falls and accumulates on the drip shield and waste package surfaces is relevant to evaluating engineered barrier component performance described in Section 2.3.5.1. Currently, localized corrosion on the drip shield surfaces and waste package outer surface due to dust deliquescence is excluded from the total system performance assessment on the basis of low consequence to repository performance. Dust buildup monitoring is relevant to confirm this screening justification.

In order to evaluate the effects of the dust deliquescence process, sampling was undertaken in the ESF. The major element compositions of the bulk dust samples were similar to those of the repository host rock, indicating that the dust is dominated by finely comminuted rock produced during excavation and construction (SNL 2008a, Section 3.3.1.10).

Dust enrichment in carbonates, manganese oxides, hydroxides, and fluorite from fracture and cavity coatings was observed. Water-soluble anions and cations comprise less than 0.5% of the total. Calcium, sodium, and potassium are the major cations, and sulfate, nitrate, and chloride are the major anions (carbonate was not analyzed). These compositions represent salts derived from atmospheric aerosols, native pore water, and construction water evaporation (Section 2.3.5.1) (SNL 2008a, Section 3.3.1.10).

The dust leachate compositions are used as input for determining the compositions of brines that might form by deliquescence on the drip shield and waste package and under what conditions, such as relative humidity and temperature, those brines could occur.

Baseline information and expected variability will be developed from the analysis and model reports on in-drift physical and chemical environments (SNL 2008a, Section 3.3.1.10).

Methodology—Waste package and drip shield material specimens exposed in emplacement drifts will be collected and analyzed to measure the actual salts that are present in the dust. Dust will also be collected at locations in the thermally accelerated drift, as appropriate, to enhance the understanding of dust distribution (SNL 2008a, Section 3.3.1.10).

The conceptual plan is to use a remotely operated vehicle equipped with cameras and remote sampling devices. The cameras may be designed to provide a visual image of the sampling activity. The remote sampling device would provide a mechanism to obtain the dust sample for laboratory analysis (SNL 2008a, Section 3.3.1.10).

4.2.1.11 Thermally Accelerated Drift In-Drift Environment Monitoring

This activity includes monitoring and laboratory evaluation of gas composition; water quantities, composition, and ionic characteristics (including thin films); microbial types and amounts; and radiation and radiolysis effects within a thermally accelerated drift. Results from this activity will be used to evaluate in-drift conditions, in conjunction with information from the thermally accelerated drift near-field monitoring and thermally accelerated drift thermal-mechanical monitoring activities. This activity will be initiated during operations, continuing until closure (SNL 2008a, Section 3.3.1.11).

Purpose—This activity provides information to evaluate the in-drift physical and chemical environment. Confirmation of the environment that surrounds the waste package container and drip shield supports evaluating the performance lifetimes of these EBS components. The major degradation mode that can affect the performance of these components is corrosion, and the kinds of corrosion and the rates of corrosion are dependent, in part, on the emplacement environment (SNL 2008a, Section 3.3.1.11).

Description of Current Understanding—Testing was conducted during site characterization to evaluate the expected emplacement environment in the Drift Scale Test conducted in the ESF (Section 2.3.3.3). Testing simulated thermal-hydrologic-chemical coupled processes to provide confidence in models (Section 2.3.3.3). The Drift Scale Test heat was used to drive the system, and measurements of results allowed validation of the thermal hydrologic-chemical model. (Section 2.3.3.3).

Established baseline information is not available at this time, especially as it relates to conditions created by actual waste packages, although data specifically from the Drift Scale Test will be used initially. Thermally induced property monitoring activities similar to this have been conducted during site characterization. This specific performance confirmation activity will not begin until the thermally accelerated drift is constructed and waste packages are emplaced.

Baseline data for this activity will be synthesized from information in analysis and model reports (SNL 2008a, Section 3.3.1.11). The performance confirmation test plan for thermally accelerated in-drift environment will draw on lessons learned from site characterization testing, such as the Drift Scale Test.

Methodology—A remote monitoring device will be used to obtain data to evaluate the environmental conditions as quantitative parameters that allow assessment of corrosion types and rates. These activities will be initiated within the thermally accelerated drift during operations, continuing until closure (SNL 2008a, Section 3.3.1.11).

As demonstrated in the Drift Scale Test, the technology to provide a remote means to make measurements in bulkheaded alcoves is available. However, the high-temperature and high-radiation environments representative of postemplacement conditions in a thermally accelerated drift require integration of specific technology applications to accomplish measurements and inspections (SNL 2008a, Section 3.3.1.11).

4.2.2 Geotechnical and Design Monitoring and Testing

[NUREG-1804, Section 2.4.3: AC 1(1), AC 2]

The Performance Confirmation Program includes a continuing program of surveillance, geotechnical testing, and geologic mapping to confirm geotechnical and design parameters, as described in this section, as well as evaluation of thermal effects on geotechnical parameters. Additional activities designed to monitor the response of the underground facility during operation until permanent closure are described in Section 4.2.1.8. Both periodic drift inspections (Section 4.2.1.8) and thermally accelerated drift thermal-mechanical monitoring (Section 4.2.2.4) are planned.

Geotechnical and design monitoring and testing will occur during construction and operations, and involves the following:

- Monitoring of subsurface conditions.
- Identification of the geotechnical and design parameters to be monitored or measured. Specific geotechnical and design parameters planned to be measured or observed will be identified in performance confirmation test plans.
- Identification of interactions between natural and engineered systems to be monitored or measured. Specific interactions between natural and engineered systems planned to be measured or observed will be identified in performance confirmation test plans.
- Comparison of measurements and observations with the original design bases and assumptions.
- Comparison of performance confirmation monitoring and measurement results with the original design bases and assumptions (e.g., ground conditions significantly different from assumed) to determine the need for design modifications and construction method changes, if necessary, as described in Section 4.1.3.
- Evaluation of the significance of performance confirmation monitoring and measurement results, as described in Section 4.1.3.
- Reporting performance confirmation results and the evaluation of impacts on repository performance. The evaluations could lead to recommended design or construction method changes to the NRC, as described in Section 4.1.1.

4.2.2.1 Subsurface Mapping

This activity includes mapping of fractures, faults, stratigraphic contacts, and lithophysal characteristics. This activity provides information to support the basis for evaluating the performance of the Upper Natural Barrier and Lower Natural Barrier in the vicinity of the repository drifts and mains by observing subsurface conditions with respect to those in the geologic framework model, which was used to develop the unsaturated zone flow models (Section 2.3.2). This activity will be conducted in the subsurface and begins with construction, continuing as new underground openings are exposed (SNL 2008a, Section 3.3.2.1).

Purpose—The purpose of this activity is to confirm the actual subsurface conditions encountered during construction. Underground geologic mapping ensures that observed variations from the expected geologic conditions described in the license application are documented and provides the basis to evaluate the information on the geologic framework that was used to model and evaluate the performance of the natural systems of the repository (SNL 2008a, Section 3.3.2.1).

Description of Current Understanding—The detailed site stratigraphy, collected from surface mapping, boreholes, and underground mapping, is integrated into model stratigraphic units that represent anticipated subsurface conditions and are used to construct models pertinent to performance assessment and repository design. A detailed hydrogeologic stratigraphy based on hydrogeologic properties of the lithostratigraphic units has been developed for use in flow and transport modeling (Section 2.3.2.3).

The baseline data for mapping will be based on the integrated site model (SNL 2008a, Section 3.3.2.1).

Methodology—Fracture characteristics will be recorded. Fault characteristics such as amounts of offset, thickness, and types of fault breccia or rubble, angularity and size of clasts, and infilling will be noted. Lithostratigraphic contacts and lithophysal characteristics will be collected (SNL 2008a, Section 3.3.2.1).

Similar mapping will be conducted in nonemplacement drifts. Data will be collected with the permanent ground support in place. Mapping will also be conducted in shafts, and will be performed from the shaft sinking equipment or the shaft support infrastructure (SNL 2008a, Section 3.3.2.1).

4.2.2.2 Seismicity Monitoring

This activity includes monitoring regional seismic activity to confirm the site seismicity characteristics used to model ground motion for assessing repository performance. Seismicity monitoring began during site characterization. It is anticipated that the existing seismic monitoring system will be maintained through repository closure. The network includes a subsurface monitoring station in the ESF to allow evaluation of ground motion within the underground facility (SNL 2008a, Section 3.3.2.2).

Purpose—The purpose of this activity is to assess the regional seismic activity that is used in simulations of the seismic disruption scenario, relevant to evaluation of the EBS. The assessment of seismic hazards at Yucca Mountain focuses on characterizing the potential for rockfall, vibratory ground motion, and fault displacement that could be associated with earthquake activity in the vicinity of the site, as described in Section 2.3.4.

Description of Current Understanding—The technical basis for evaluating seismic hazards is described in Section 2.3.4.5 which discusses the probabilistic seismic hazard analysis process and results. Tectonic models proposed for the area and information from analogue sites in the Basin and Range Province provide additional context in which to characterize the patterns of seismicity. The probabilistic assessment explicitly incorporates uncertainties in the characterization of seismic sources, fault displacement, and ground motion (Section 2.3.4). The resulting hazard calculations represent the basis for seismic design and performance assessment (SNL 2008a, Section 3.3.2.2).

Baseline information for this activity is well established. A catalog of historical and instrumentally recorded earthquakes was compiled for the region within 300 km of the repository site at Yucca Mountain (SNL 2008a, Section 3.3.2.2).

Methodology—A detailed description of the methodology is provided in *Performance Confirmation Test Plan for Seismicity Monitoring* (SNL 2007a). In the event of a large earthquake, inspections and investigations of possible damage to the underground openings and any evidence of fault displacements will be accomplished in ways that depend on the timing of any seismic event and the state of repository construction and operations at the time of each event. There are at least three sets of locations where measurements and/or observations may be conducted following significant seismic events as defined in the test plan (SNL 2007a). These three locations are: (1) site characterization locations; (2) locations that exhibit unusual characteristics (unusual lithophysae, stratigraphic contact areas, fault zone areas); and (3) areas identified during the course of performing other performance confirmation activities (e.g., unexpected rock properties, evidence of ground support distress). Investigations of possible damage to underground openings will be performed in accordance with the performance confirmation technical work plans for construction effects monitoring (BSC 2006) Monitoring of underground openings for rockfall or ground support damage may be initiated in response to seismic events. Parameters and condition limits are included in performance confirmation test plans for construction effects monitoring (BSC 2006) and seismicity monitoring (SNL 2007a) and will be included for routine drift inspection *Performance Confirmation Plan* (SNL 2008a, Section 3.3.2.2).

4.2.2.3 Construction Effects Monitoring

This activity includes instrumenting mined openings to detect construction-induced deformation. It supports the confirmation of key geotechnical parameters used in the design of the mined openings. Confirmation of these parameters confirms the assumptions that led to the analysis of stability of the openings. Similar monitoring began during site characterization and will continue throughout construction. Construction effects monitoring in emplacement drifts will cease when waste is emplaced. Long-term monitoring in mains and shafts is expected to continue until closure (SNL 2008a, Section 3.3.2.3).

Purpose—The purpose of this activity is to monitor and confirm the mechanical response of the emplacement and main drift excavations, thereby confirming stability and retrievability. Measured deformations will be used to estimate rock mass mechanical properties. Regular monitoring of subsurface openings for significant rock fall occurrence is also performed. Since this activity is conducted prior to waste emplacement, only mechanical responses at ambient temperatures will be monitored. The performance confirmation test plan for construction effects monitoring describes the objectives (BSC 2006).

Description of Current Understanding—Past construction monitoring in the ESF and ECRB Cross-Drift primarily focused on an ongoing assessment of drift stability. Measurement components from that activity included strain gauges, tunnel convergence pins (vertical and horizontal), multipoint borehole extensometers, single-point borehole extensometers, and rock bolt load cells (SNL 2008a, Section 3.3.2.3). Convergence of vertical openings is measured with multipoint borehole extensometers. These data will be used to confirm primarily that the predicted rock mass modulus parameter is within the expected range.

Mechanical rock property information on the intact rock has been determined through laboratory testing. The rock properties measured show that the rock matrix material is typically strong and elastic; however, the rock mass modulus (rock matrix including fractures, jointing) largely defines the properties and overall rock mass mechanical response to thermal and mechanical loading, as described in Section 2.3.4, and is thereby considered a key geotechnical parameter. Rock material properties are discussed in Sections 1.1.5.3 and 2.3.4.4.2. Additional primary stability assessment will be ascertained by regular inspection of subsurface excavations for significant rock fall occurrence.

Baseline information from several site characterization data sources noted above, along with geotechnical design and model analyses, were used in quantifying rock properties parameters to be used in evaluation of performance confirmation data. Comparisons will indicate whether the ranges for the parameters measured in situ are consistent with the data used in conceptual models and ranges used in numerical models relevant to drift stability and design (SNL 2008a, Section 3.3.2.3).

Methodology—Monitoring construction effects includes convergence pins, multipoint extensometers, and single-point extensometers. Plans for construction monitoring of rock mass response in the repository main and emplacement drifts draw from experience acquired during construction and monitoring in the ESF and ECRB Cross-Drift. Rock mass mechanical properties will be estimated from measured deformations using calculated or assumed loading of excavated drifts. The construction effects monitoring performance confirmation test plan acknowledges that new test equipment and testing and monitoring methods will be considered as underground openings are constructed (BSC 2006). The performance confirmation test plan will be updated as necessary to reflect such new equipment or methods.

4.2.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring

This activity includes monitoring drift and invert degradation in the thermally accelerated drift. It contributes to confirmation of information on the environment for components of the EBS. Results from this activity will incorporate thermal load effects and will be used in conjunction with results from the construction effects monitoring (Section 4.2.2.3) and drift inspection activities (Section 4.2.1.8) (SNL 2008a, Section 3.3.2.4).

Purpose—The purpose of this activity is to assess drift degradation assumptions under thermal conditions by monitoring the deformation of the thermally accelerated drift periphery and invert. This deformation, which will be measured remotely, will be used to assess the degradation and mechanical stability, thus providing an indication of overall drift stability (SNL 2008a, Section 3.3.2.4).

Description of Current Understanding—Construction monitoring in the ESF and ECRB Cross-Drift primarily focused on an ongoing assessment of drift stability. Tunnel conditions have been stable since excavation. Thermomechanical properties of intact rock and fractures from the repository host horizon units are also available from laboratory testing. The rock matrix material is typically strong and elastic; thus, the rock mass structure largely defines the properties and overall rock mass mechanical response to thermal and mechanical loading. Ranges and distributions for geotechnical parameters used in both pre-closure design and post closure analysis are discussed in Sections 1.1.5.3 and 2.3.4.4.2.

Established baseline information is not available for this activity because similar activities have not been conducted under conditions created by the presence of waste packages. However, thermally induced rock property monitoring activities similar to this one have been conducted during site characterization. This specific performance confirmation activity will not begin until the thermally accelerated drift is constructed and waste packages are emplaced (SNL 2008a, Section 3.3.2.4).

Methodology—Conventional measurements of vertical and horizontal closure were made as part of testing in the ESF. Because of physical interference, similar convergence measurements will not be possible with waste packages in place. This activity will use technology consisting of remote monitoring, such as cameras and lasers, providing for observations and deformation monitoring along the periphery of the accelerated drift and the invert. Extensometer-based instrumentation and other techniques may also be considered (SNL 2008a, Section 3.3.2.4).

The technology to provide a remote means to monitor drift deformation is available. However, the high-temperature and high-radiation environments representative of postemplacement conditions in the thermally accelerated drift require development of specific applications of the technology (SNL 2008a, Section 3.3.2.4).

4.2.3 Design Testing Other than Waste Packages

[NUREG-1804, Section 2.4.3: AC 3]

The Performance Confirmation Program for testing engineered systems and components used in the design will be developed and initiated as early as practicable during construction, and will continue into the operational period. It will include evaluation of materials and design for drip shields, as described in Section 1.3.4. Materials and design of the backfill material for the ramps and shafts will be evaluated once material and placement specifications are provided prior to initiation of closure operations (Section 1.3.6). The repository subsurface design basis (Section 1.3) has designated that sealing of shafts and ramps will be accomplished by backfilling (BSC 2008, Parameter 09-01), and sealing of boreholes will be accomplished by backfilling and plugging (BSC 2008, Parameter 09-03). Emplacement drifts, access drifts, exhaust drifts, and the connecting turnouts, will not be backfilled. Backfill will be emplaced along the entire length of each ramp and over the entire depth of each shaft. Boreholes will be backfilled with material that is compatible with the host rock, and plugged. These measures are the intended actions for repository permanent closure (10 CFR 63.2). Drift stability, water intrusion, and magma flow between drifts were not important design testing considerations because closure of shafts, ramps, and boreholes by these measures has been determined not to be important to barrier capability (Section 2.1) and not important to waste isolation (Section 1.9). Testing of thermal interaction effects between waste packages, drip shields, host rock, and drift seepage will be conducted as described in Sections 4.2.1.8, 4.2.1.9, 4.2.1.11, and 4.2.2.4.

4.2.3.1 Seal and Backfill Testing

This activity includes laboratory testing of the effectiveness of borehole seals, field testing of the effectiveness of ramp and shaft seals, and field testing of backfill placement and compaction procedure effectiveness as appropriate for the manner in which backfill is incorporated in the repository design. This confirmatory testing activity will be conducted before full scale operation proceeds to backfilling of shafts and ramps, or backfilling and plugging of boreholes. Testing to evaluate the effectiveness of backfill placement and compaction procedures will be conducted before beginning permanent backfill placement, using methods that will be demonstrated to be commensurate with the importance of backfilling to postclosure waste isolation performance. Performance-based analysis, and the experience base available for backfill preparation and placement, will be used as applicable to confirm that the testing approach is justified. Use of laboratory and in situ testing methodologies will be evaluated and determined in the development of the test plan for the confirmation activity. It will include evaluation of materials and designs for the borehole, shaft, and ramp seals. Testing backfill procedures will be conducted during repository operations, if implemented (SNL 2008a, Section 3.3.3.1).

Laboratory tests on borehole seals will be completed during the early developmental stage of construction. Field testing of the effectiveness of ramp and shaft seals will be completed prior to submittal of an application for a license amendment for permanent closure (SNL 2008a, Section 3.3.3.1).

As noted, backfill is not included in the repository emplacement drift design. Tests to evaluate the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun are included in the seal testing activity.

Purpose—The purpose of the performance confirmation borehole, shaft, and ramp seals testing activities is to evaluate design assumptions for implementation of backfilling and plugging measures to effect permanent repository closure (SNL 2008a, Section 3.5.5[a]). Seal and closure systems will be evaluated for their effectiveness and compatibility with the subsurface environment. Backfill placement and compaction procedures will be evaluated against design requirements (SNL 2008a, Section 3.3.3.1).

Description of Current Understanding—Sealing of shafts, ramps, and boreholes will be conducted as part of closure of the repository. Shafts, ramps and boreholes will be backfilled, and the boreholes will then be capped with a concrete (or alternate material) plug(s) at preselected locations. The design for ramp and shaft seals will be finalized using information from construction measurements and observations (SNL 2008a, Section 3.3.3.1).

Information for the performance, testing, analysis, placement, and compaction of backfill materials used to seal the shafts, ramps and boreholes is widely available in the engineering literature and will be used to develop baseline information, as appropriate (SNL 2008a, Sections 3.3.3.1 and 3.6.1).

Methodology—Laboratory and field tests will be used to evaluate the effectiveness of backfill placement and compaction procedures against design requirements (SNL 2008a, Section 3.3.3.1). The borehole seal testing aspect of this activity is not expected to adversely affect the ability of the repository to meet performance objectives because disturbances from obtaining samples is limited and occurs in a small portion of the repository. Further, several elements of these design tests can be executed outside the repository footprint. The potential for adverse effects on repository performance for the borehole seal testing and field testing of shaft and ramp seals will be conducted during the detailed test planning applicable to these activities (SNL 2008a, Section 3.3.3.1).

4.2.4 Monitoring and Testing of Waste Packages

[NUREG-1804, Section 2.2.1.3.4.3: AC 5(4); Section 2.4.3: AC 4]

Performance confirmation activities include provisions for selective monitoring of the condition of representative waste packages following emplacement in the repository. Activities to ensure waste packages are placed in compliance with the conditions analyzed in the performance assessment will be controlled through the waste package loading plans, which will be addressed by License Specifications (Section 5.10). The activities described in Sections 4.2.1.9, 4.2.1.10, and 4.2.1.11 are designed in part to provide for the monitoring of emplaced waste packages that are representative in terms of materials, design, structure, fabrication, inspection methods, and environment. The environmental conditions monitored in the activities described in Sections 4.2.1.9, 4.2.1.10, and 4.2.1.11 address coupled thermal-hydrologic-chemical processes that affect the amount and chemistry of the water and other environmental variables. Monitoring and testing of waste packages will continue as long as practical until permanent repository closure (SNL 2008a, Section 3.3.4).

Performance confirmation activities include remote monitoring of a representative set of waste packages, as well as provisions for laboratory testing of waste package and drip shield materials representative of those emplaced in the repository. These performance confirmation activities focus on corrosion testing of waste package and drip shield materials, as well as internal waste package conditions. To the extent practicable, the laboratory experiments will be designed to include representative repository emplacement environments. These laboratory tests are expected to confirm the design basis for the waste package and confirm information that supports modeling of waste package and drip shield performance. Waste package monitoring includes corrosion monitoring but is not limited to the use of corrosion coupons (SNL 2008a, Section 3.3.4).

These activities continue the laboratory engineered materials testing that began during site characterization, and will continue through repository construction and operation periods. The focus is on evaluating fabrication materials for the waste packages and drip shields in the environments relevant to performance of these components. Testing for both waste package and drip shield materials is presented in this section because of the similarities in the testing approaches (SNL 2008a, Section 3.3.4).

The principal purpose of corrosion testing activities is measurement of the general corrosion rate and an evaluation of the overall corrosion performance of the waste package outer barrier material and the drip shield material. One activity will consist of exclusively laboratory-based tests that are a continuation of current corrosion testing. The other activity will involve test specimen exposure in the thermally accelerated drift, with subsequent specimen characterization and analyses performed in the laboratory. The tests are designed to provide information on localized corrosion and dust-related effects, in addition to general corrosion (SNL 2008a, Section 3.3.4).

Information about resistance of test materials to localized corrosion and to environmentally accelerated cracking is expected to be obtained. Analysis of the passive film structure and composition will evaluate information used in thermodynamic calculations, indicating that a stable, passive film maintains low general corrosion rates and provides protection from localized corrosion and environmentally accelerated cracking (SNL 2008a, Section 3.3.4).

The scope of the Performance Confirmation Program does not include operational and administrative controls of processes such as materials qualification, waste acceptance, or waste package testing and handling. Section 5.6 addresses plans for the conduct of normal activities, including maintenance, surveillance, and routine periodic testing of structures, systems, and components and processes, based on the preclosure safety analysis and the performance assessment.

4.2.4.1 Waste Package Monitoring

This activity includes remote monitoring of external corrosion of waste packages. The activity will monitor selected representative waste packages located in the repository emplacement drifts. This activity will be initiated early during waste emplacement operations (SNL 2008a, Section 3.3.4.1).

Purpose—The purpose of this activity is to confirm the condition of selected representative waste packages. This activity may be conducted using remote monitoring for external corrosion, or other technologies that will be evaluated at the time of test planning.

Description of Current Understanding—Waste packages and their components are described in Section 1.5.2. Intact waste packages prevent contact between water and the waste form and cladding, and they limit water flow and potential radionuclide movement, even with less-than-complete integrity. The waste packages have a dual-layer design consisting of two concentric cylinders, as described in Section 1.5.2.1. Commercial SNF waste packages include a transportation, aging, and disposal canister, as well, that is also described in Section 1.5.2. Analyses of the potential for waste package corrosion are described in Section 2.3.6. Analyses of the potential for early failure of waste packages resulting from manufacturing defects or operational processes are described in Section 2.3.6.6. These analyses indicate that waste packages prevent or substantially reduce the release of radionuclides (Section 2.1.2.2).

The baseline data for this activity will be synthesized from performance assessment results, as well as from information obtained from analysis and model reports (SNL 2008a, Section 3.3.4.1).

Methodology—The field waste package monitoring, including the number of packages monitored, locations, durations, and design of the testing, and waste packages selected for underground monitoring will represent those to be emplaced in terms of materials, design, structure, fabrication, and inspection methods. This monitoring and inspection may consist of remote visual observation of waste package conditions, or other technologies that will be evaluated at the time of test planning (SNL 2008a, Section 3.3.4.1).

Planning for this activity is conceptual, and other methods and approaches may be employed. The technology to provide a remote means to monitor emplaced waste is available. Performance confirmation monitoring will be integrated with underground operations to develop a compatible remotely operated vehicle or other monitoring technology compatible with operations (Section 1.3.4). The high-temperature and high-radiation environments representative of postemplacement conditions require integration of specific technology applications to accomplish measurement and inspections (SNL 2008a, Section 3.3.4.1).

4.2.4.2 Corrosion Testing

This activity includes laboratory exposure of waste package, emplacement pallet, and drip shield samples in the range of representative repository environments, as well as attendant characterization and analyses to evaluate the type, rate, and morphology of corrosion. Testing and analyses for this activity are conducted in the laboratory. This activity began during site characterization and will continue until closure (SNL 2008a, Section 3.3.4.2).

Purpose—The purpose of this activity is to confirm information used to evaluate the performance of the materials that will be used to fabricate the waste package, emplacement pallet, and drip shield components of the EBS. This activity will assess results of corrosion models by measurement of the general corrosion rate and evaluation of the overall corrosion performance of the waste package outer barrier material and the drip shield material. Test specimens will be selected to be representative of the as-fabricated waste package, emplacement pallet, and drip shield materials to be emplaced in the repository (SNL 2008a, Section 3.3.4.2).

Description of Current Understanding—The waste package and its components are described in Section 1.5.2. Analyses of waste package and drip shield corrosion are described in Section 2.3.6. These analyses indicate that these features prevent or substantially reduce releases of radionuclides (Section 2.1.2.2).

General corrosion is the background degradation mode for waste package and drip shield materials. Alloy 22 (UNS N06022), Stainless Steel Type 316L, and titanium were selected for their anticipated low general corrosion rates in expected repository environments (Section 2.3.6). This activity will obtain general corrosion information from analysis of test specimens exposed in laboratory environments. Qualitative and semiquantitative information on resistance to localized corrosion and to environmentally accelerated cracking can also be obtained.

The baseline data for this activity will be synthesized from performance assessment results and from analysis and model reports (SNL 2008a, Section 3.3.4.2).

Methodology—Tests conducted up to the point of license application are considered and evaluated in the process for developing a long-term corrosion testing strategy. Information from testing that is used to support the license application will be assessed, and test guidelines will be developed on the basis of testing performed to date. A long-term strategy will identify the requisite facilities to evolve and enhance existing data. A subset of the long-term corrosion test matrix will be identified for the purpose of confirming corrosion information used for the licensing basis. The process for performance confirmation test planning utilizes the most recent performance assessment and performance margin analyses to establish the relevant testing materials and conditions. The planned laboratory testing has three aspects: long-term corrosion tests, thermal aging tests, and electrochemical testing.

Long-Term Corrosion Testing—The purpose of this aspect of the activity is to continue obtaining corrosion data from a series of planned interval tests begun during site characterization. A large number of specimens was emplaced in the test vessels and later removed at various predetermined intervals. Measurements were made of weight loss that occurred during the time interval the specimen was exposed to the test solution (SNL 2008a, Section 3.3.4.2). Methods for corrosion testing follow standard practices of the American Society for Testing and Materials, with modifications made to accommodate repository-specific conditions and requirements described in the test plans. A scanning electron microscope may be used to analyze samples, including the composition of the surface. As needed, other surface analytical tools can be used to evaluate features, such as the structure and change in composition as a function of depth (SNL 2008a, Section 3.3.4.2).

Thermal Aging—The thermal aging tests began during site characterization, operating five furnaces at constant temperatures (400°C, 500°C, 550°C, 600°C, and 650°C) in air.

These tests evaluate phase transformations in Alloy 22 that can affect performance of the material in the repository environment. Testing addresses whether these transformations occur at the comparatively lower temperatures in the repository over longer periods. Models project that these transformations do not occur to a significant extent in the base metal. Testing to confirm a similar expectation for welded and cold-worked material is included (SNL 2008a, Section 3.3.4.2).

The thermal aging facility also provides test specimens for other parts of long-term corrosion and electrochemical-based tests, so an appropriate range of metallurgical conditions is evaluated in this testing (SNL 2008a, Section 3.3.4.2).

Electrochemical Testing—Electrochemical testing, using measurements of potential and current is useful for determining localized corrosion susceptibility. It can also provide alternative and more sensitive techniques to the weight-loss method for measuring general corrosion. Because electrochemical testing is typically of short duration (on the order of a day to a few weeks) when compared to the long-term corrosion tests (on the order of months to several years), many more experimental variables can be studied in a series of electrochemical tests to evaluate material performance in a repository setting (SNL 2008a, Section 3.3.4.2).

Electrochemical testing can be used to measure properties such as open circuit potential and critical potential. Information on these properties forms the basis for models used to predict performance. The difference in value between the critical potential and the open-circuit potential is the basis for describing the susceptibility of a material to localized corrosion in a given environment (SNL 2008a, Section 3.3.4.2).

This work has used a variety of techniques, most of which are based on American Society for Testing and Materials methods, with some modification for repository-specific circumstances described in the test plans. These techniques will continue to be used for these performance confirmation activities (SNL 2008a, Section 3.3.4.2).

Planning for this activity is evolving; other methods and approaches may be employed and the details of test implementation will be included in the individual performance confirmation test plans (SNL 2008a, Section 3.3.4.2).

4.2.4.3 Corrosion Testing of Thermally Accelerated Drift Samples

This activity exposes engineered materials to the environment of the thermally accelerated drift. To the extent practicable, the subsequent analysis of samples from this activity will be the same as corrosion testing under laboratory conditions (Section 4.2.4.2).

Purpose—The purpose of this activity is to confirm information used to evaluate corrosion models. Similar in purpose to the activity for corrosion testing in the laboratory (Section 4.2.4.2), the primary objective of this activity is measurement of the general corrosion rate and an evaluation of the overall corrosion performance of the waste package outer barrier material and the drip shield material. The activity will involve exposure of test samples in the thermally accelerated drift, with subsequent sample characterization and analyses performed in the laboratory. The samples will be representative of the waste package and drip shield materials (the same materials as in the design) (SNL 2008a, Section 3.3.4.3).

Description of Current Understanding—The waste package and its components are described in Section 1.5.2. Analyses of waste package and drip shield corrosion are described in Section 2.3.6. These analyses indicate that these features prevent or substantially reduce releases of radionuclides (Section 2.1.2.2). In situ testing similar to that included in this activity has not been conducted during site characterization.

After exposure in the thermally accelerated drift, specimens will be withdrawn periodically for subsequent analysis and characterization in a laboratory. Test specimens will be representative of the waste package and drip shield materials to be emplaced in the repository.

The baseline data for this activity will be synthesized from performance assessment results and from analysis and model reports (SNL 2008a, Section 3.3.4.3).

Methodology—This activity exposes test specimens in the thermally accelerated drift. Specimens will be emplaced in the drift and later removed. Methods of placement and retrieval will be developed as the test details are developed. After exposure in the thermally accelerated drift for periods of several years, and up to the length of time before the repository is closed, periodic withdrawals of samples will be made for subsequent analysis and characterization in a laboratory setting. Specimen characteristics, postexposure characterization, and analyses will be consistent with those proposed for the laboratory testing (Section 4.2.4.2). Evaluation of localized corrosion and environmentally accelerated cracking will follow the standard practices of the American Society for Testing and Materials, with modifications made to accommodate repository-specific conditions and requirements as described in the test plans (SNL 2008a, Section 3.3.4.3). Planning for this activity is conceptual; other methods and approaches may be employed and further described in the performance confirmation test plan.

4.2.4.4 Waste Form Testing

This activity includes waste form testing and will include waste package coupled effects in the laboratory under simulated internal waste package conditions. Certain analytical elements of this activity began during site characterization and will be expanded to include a simulated waste package, with tests continuing until at least the early stages of waste emplacement (SNL 2008a, Section 3.3.4.4).

Purpose—The purpose of this activity is to evaluate results of waste form degradation models and evaluate in-package conditions. These laboratory tests focus on the internal conditions of the waste package. The dissolution rate of the waste form in an aqueous environment is evaluated to assess the time required to release radionuclides from the waste forms. Water chemistry, temperature, and corrosion of internal metallic components within the waste package could affect the degradation rate of the SNF and HLW (SNL 2008a, Section 3.3.4.4).

Description of Current Understanding—Elements of waste form testing began during site characterization. The waste package and its components, including waste forms, are described in Section 1.5. The waste forms that will be disposed of include SNF and HLW. Commercial SNF and HLW are solid materials that degrade slowly in the unsaturated environment, thus reducing the release rate of radionuclides (Section 2.1.1.2).

Waste form testing in the performance confirmation period will seek to measure chemical and physical changes occurring inside waste packages. Movement of liquid or vapor-phase water through cracks in the waste package can initiate coupled processes, including degradation of fuel and steel components inside the package. The interacting processes control the availability of water in the waste package, the pH in the package and, by extension, the solubility and colloid mobility of dose-critical radionuclides (SNL 2008a, Section 3.3.4.4).

The coupled nature of waste package source-term processes prevents the details of the process from being readily estimated, resulting in uncertainties associated with the waste package source-term models. This activity will provide information to confirm the assumptions used in the license application for waste package source-term models used in performance assessments (SNL 2008a, Section 3.3.4.4).

The baseline data for this activity will be synthesized from performance assessment results, as well as from analysis and model reports (SNL 2008a, Section 3.3.4.4).

Methodology—A series of tests under relevant repository conditions will be conducted. Conservative test conditions using water are expected. Water accumulation from humid air exposure, water chemistry, and mobile fractions of dose-critical radionuclides will be measured using mock-ups of waste packages. Planning for this activity is conceptual; other methods and approaches may be employed (SNL 2008a, Section 3.3.4.4).

4.3 GENERAL REFERENCES

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SNL 2007c. *Saturated Zone Site-Scale Flow Model*. MDL-NBS-HS-000011 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070626.0004.

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Table 4-1. Performance Confirmation Activity Relationships to Performance Assessment Parameters, Purpose, Barrier, or Event

Type of Monitoring and Testing	Candidate Activity	Activity Description	Candidate Parameters	Purpose	Barrier or Event	SAR Section
General Requirements Testing and Monitoring (Natural and Engineered Barriers)	Precipitation monitoring[a]	Monitoring of precipitation and composition analysis	Precipitation (rate and/or quantity), precipitation chemical composition	To evaluate the precipitation input parameter that relates to seepage modeling	Upper Natural Barrier	4.2.1.1
	Seepage monitoring[a]	Seepage monitoring and laboratory analysis of water samples (from bulkheaded alcoves on the intake side of the repository and in thermally accelerated drift)	Seepage rate, locations, quantity and chemical composition, vent air barometric pressure, vent air temperature, vent air relative humidity	To evaluate results from the seepage model	Upper Natural Barrier	4.2.1.2
	Subsurface water and rock testing[a]	Laboratory analysis of chloride concentration and isotope chemistry based on samples taken at selected locations of the underground facility	Chloride concentration; isotopic composition for U, Sr, O, ^{3}H, $^{36}Cl/Cl$, ^{99}Tc, and $^{129}I/^{127}I$	To evaluate assumptions for fast paths used in unsaturated zone model	Upper Natural Barrier, Lower Natural Barrier	4.2.1.3
	Unsaturated zone testing[a]	Testing of transport properties and field sorptive properties of the crystal-poor member of the Topopah Spring Tuff, in an ambient seepage alcove or a drift	Sorption parameters, van Genuchten parameters describing fractures and matrix, colloid/colloid-facilitated transport parameters, fracture density, apertures, coatings, air permeability, seepage, alcove temperature, and relative humidity	To evaluate sorption coefficients used in unsaturated zone model	Upper Natural Barrier, Lower Natural Barrier, EBS	4.2.1.4
	Saturated zone monitoring[a]	Monitoring of water level and hydrochemical sampling of the saturated zone upgradient, beneath, and downgradient of Yucca Mountain	Water level and hydrochemical indicators (Eh, pH, radionuclide concentrations, colloid characteristics)	To evaluate hydrologic and chemical parameters used with the saturated zone flow model	Lower Natural Barrier	4.2.1.5

Table 4-1. Performance Confirmation Activity Relationships to Performance Assessment Parameters, Purpose, Barrier, or Event (Continued)

Type of Monitoring and Testing	Candidate Activity	Activity Description	Candidate Parameters	Purpose	Barrier or Event	SAR Section
General Requirements Testing and Monitoring (Natural and Engineered Barriers) (Continued)	Saturated zone fault testing	Hydraulic and tracer testing of fault zone hydrologic characteristics, including anisotropy, in the saturated zone	Transmissivity, hydraulic conductivity, water flux and specific discharge, effective flow porosity, longitudinal dispersivity, sorption parameters, parameters describing diffusion between flowing and stagnant water, and colloid or colloid-facilitated transport parameters; Eh, pH, natural colloid concentrations, including anisotropy	To evaluate fault parameter assumptions in the saturated zone flow and transport models	Lower Natural Barrier	4.2.1.6
	Saturated zone alluvium testing[a]	Tracer testing at the Alluvial Testing Complex using multiple boreholes measuring parameters in the alluvium	Transmissivity, hydraulic conductivity, water flux and specific discharge, effective flow porosity, longitudinal dispersivity, sorption parameters, parameters describing diffusion between flowing and stagnant water, and colloid or colloid-facilitated transport parameters; Eh, pH, natural colloid concentrations	To evaluate inputs and assumptions for the saturated zone flow and transport model	Lower Natural Barrier	4.2.1.7
	Drift inspection	Regular inspection of nonemplacement drifts and periodic inspection of emplacement drifts, the thermally accelerated drift, and other underground openings using remote measurement techniques as appropriate	Temperature (as a surrogate indicator of evaporating seepage), seepage, rockfall size and frequency monitoring, ground support conditions, engineered barrier component positions, drift continuity	To evaluate drift stability assumptions and rockfall size or probability distributions; also supports confirmation of retrievability	EBS	4.2.1.8
	Thermally accelerated drift near-field monitoring	Monitoring of near-field coupled processes (thermal-hydrologic-mechanical-chemical) properties and parameters associated with the thermally accelerated drift	Rock-mass moisture content, temperature and thermal gradients, air permeability (fracture permeability), mechanical deformation, mechanical properties, water chemistry	To evaluate results from the thermal-hydrologic-chemical-mechanical models	Upper Natural Barrier, EBS	4.2.1.9

Table 4-1. Performance Confirmation Activity Relationships to Performance Assessment Parameters, Purpose, Barrier, or Event (Continued)

Type of Monitoring and Testing	Candidate Activity	Activity Description	Candidate Parameters	Purpose	Barrier or Event	SAR Section
General Requirements Testing and Monitoring (Natural and Engineered Barriers) (Continued)	Dust buildup monitoring	Monitoring and laboratory testing of quantity and composition of dust on engineered barrier surfaces	Quantity, physical properties, and chemical composition of dust deposited on waste package, drip shield, rail, and ground support surfaces	To evaluate assumptions of dust buildup and potential chemical effects	EBS	4.2.1.10
	Thermally accelerated drift in-drift environment monitoring	Monitoring and laboratory testing of gas composition; water quantities, composition, and ionic characteristics (including thin films); microbial types and amounts; and radiation and radiolysis within the thermally accelerated drift	Temperature, relative humidity, gas composition, radionuclides, pressure, radiolysis, thin films evaluation, condensation water quantities, and composition or ionic characteristics, including microbial effects	To evaluate assumptions of in-drift physical and chemical environment models	Upper Natural Barrier, EBS	4.2.1.11
Geotechnical and Design Monitoring and Testing	Subsurface mapping[a]	Mapping of fractures, faults, stratigraphic contacts, and lithophysal characteristics	Fracture characteristics, fault zone characteristics (offset, location, age), stratigraphic contacts, and lithophysal characteristics	To evaluate results from the integrated site model	Upper Natural Barrier, Lower Natural Barrier	4.2.2.1
	Seismicity monitoring[a]	Monitoring regional seismic activity; observation of subsurface and surface (large magnitude) fault displacement after large local or regional seismic events	Event detection, event magnitude, event location, strong-motion data collection and analysis, seismic attenuation investigations (within 50 km)	To evaluate annual probability distribution as a function of magnitude and intensity	Disruptive Event	4.2.2.2
	Construction effects monitoring[a]	Monitoring construction deformation and measurement of mechanical properties	Drift convergence, tunnel stability, engineered ground support systems, geotechnical parameters at selected locations	To evaluate tunnel stability assumptions under ambient conditions, address retrievability	EBS	4.2.4.3

Table 4-1. Performance Confirmation Activity Relationships to Performance Assessment Parameters, Purpose, Barrier, or Event (Continued)

Type of Monitoring and Testing	Candidate Activity	Activity Description	Candidate Parameters	Purpose	Barrier or Event	SAR Section
Geotechnical and Design Monitoring and Testing (Continued)	Thermally accelerated drift thermal-mechanical monitoring	Monitoring drift and invert shape and integrity in the thermally accelerated drift	Drift convergence, drift shape, drift degradation, ground support visual condition, rail alignment, invert visual condition, pallet visual condition, waste package alignment, and spacing	To evaluate drift degradation assumptions and analyses under thermal conditions, address retrievability	EBS	4.2.2.4
Design Testing Other than Waste Package	Seal and backfill testing	Laboratory testing of effectiveness of borehole seals, followed by field-testing of effectiveness of ramp and shaft seals; testing, as appropriate, to evaluate the effectiveness of backfill placement	Borehole seal materials, configuration, performance; shaft seal materials, configuration, performance; ramp seal materials, configuration, performance; laboratory and field hydraulic and pneumatic seal effective permeability	To evaluate design assumptions for effective seals	EBS, Upper Natural Barrier	4.2.3.1
Monitoring and Testing of Waste Packages	Waste package monitoring	Remote monitoring for evidence of external corrosion of the waste package	External visual corrosion and possibly internal pressure of the waste package	To evaluate results from the corrosion models	EBS	4.2.4.1
	Corrosion testing[a]	Corrosion testing in the laboratory of waste package, emplacement pallet, and drip shield samples in the range of representative repository thermal and chemical environments; includes laboratory testing of general corrosion, phase transformations of Alloy 22, and localized corrosion	Measurements of Alloy 22, Stainless Steel Type 316L, and Titanium Grade 7 (UNS R56404) and Grade 29 (UNS R52400) mass loss rate, passive current density, surface dissolution, open circuit potential, critical potential, stress corrosion cracking, microbial effects, surficial passive film stability, and mechanical properties	To evaluate results of corrosion models	EBS	4.2.4.2

Table 4-1. Performance Confirmation Activity Relationships to Performance Assessment Parameters, Purpose, Barrier, or Event (Continued)

Type of Monitoring and Testing	Candidate Activity	Activity Description	Candidate Parameters	Purpose	Barrier or Event	SAR Section
Monitoring and Testing of Waste Packages (Continued)	Corrosion testing of thermally accelerated drift samples	Corrosion testing in the laboratory of waste package, emplacement pallet, and drip shield samples exposed to conditions in the thermally accelerated drift; includes corrosion model applicability and laboratory testing of general corrosion, phase transformations of Alloy 22; and localized corrosion	Measurements of thermally accelerated drift exposed Alloy 22, Stainless Steel Type 316, and Titanium Grade 7 and Grade 29 mass loss rate, passive current density, surface dissolution, open circuit potential, critical potential, stress corrosion cracking, microbial effects, surficial passive film stability, and mechanical properties	To evaluate results of corrosion models	EBS	4.2.4.3
	Waste form testing[a]	Waste form testing (including waste package coupled effects) in the laboratory under anticipated in-package conditions	Radionuclide release rate, dissolution rate, environmental and hydrochemical indicators (Eh, pH, colloid characteristics); bare waste form dissolution, fuel rod waste form dissolution, fuel rod waste package, coupled chemical environment	To evaluate results of waste form degradation models and evaluate in-package expected conditions	EBS	4.2.4.4

NOTE: [a]Performance confirmation activities that are continued from site characterization or for which similar monitoring or testing has been undertaken during site characterization.

Table 4-2. Relationship of Performance Confirmation Activities to 10 CFR 63, Subpart F, Requirements

10 CFR 63, Subpart F	Performance Confirmation Activities
10 CFR 63.131(a)(1)–Actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review; and	• Seepage monitoring (Section 4.2.1.2) • Drift inspection (Section 4.2.1.8) • Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Thermally accelerated drift in-drift environment monitoring (Section 4.2.1.11) • Subsurface mapping (Section 4.2.2.1) • Seismicity monitoring (Section 4.2.2.2) • Construction effects monitoring (Section 4.2.2.3) • Thermally accelerated drift thermal-mechanical monitoring (Section 4.2.2.4)
10 CFR 63.131(a)(2)–Natural and engineered systems and components required for repository operation, and that are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated.	• Precipitation monitoring (Section 4.2.1.1) • Seepage monitoring (Section 4.2.1.2) • Subsurface water and rock testing (Section 4.2.1.3) • Unsaturated zone testing (Section 4.2.1.4) • Saturated zone monitoring (Section 4.2.1.5) • Saturated zone fault hydrology testing (Section 4.2.1.6) • Saturated zone alluvium testing (Section 4.2.1.7) • Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Dust buildup monitoring (Section 4.2.1.10) • Thermally accelerated drift in-drift environment monitoring (Section 4.2.1.11) • Subsurface mapping (Section 4.2.1.1) • Seismicity monitoring (Section 4.2.2.2) • Construction effects monitoring (Section 4.2.2.3) • Thermally accelerated drift thermal-mechanical effect (Section 4.2.2.4) • Seal and backfill testing (Section 4.2.3.1) • Waste package monitoring (Section 4.2.4.1) • Corrosion testing (Section 4.2.4.2) • Corrosion testing of thermally accelerated drift samples (Section 4.2.2.3) • Waste form testing (Section 4.2.4.4)
10 CFR 63.131(b)–The program must have been started during site characterization, and it will continue until permanent closure.	• Program objectives and overview (Section 4.1)
10 CFR 63.131(c)–The program must include in situ monitoring, laboratory and field testing, and in situ experiments, as may be appropriate to provide the data required by paragraph (a) of this section.	• Program objectives and overview (Section 4.1)
10 CFR 63.131(d)(1)–It does not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives.	• Program implementation (Section 4.1.1)

Table 4-2. Relationship of Performance Confirmation Activities to 10 CFR 63, Subpart F, Requirements (Continued)

10 CFR 63, Subpart F	Performance Confirmation Activities
10 CFR 63.131(d)(2)–It provides baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities.	• Program implementation (Section 4.1.1)
10 CFR 63.131(d)(3)–It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository.	• Program implementation (Section 4.1.1)
10 CFR 63.132(a)–During repository construction and operation, a continuing program of surveillance, measurement, testing, and geologic mapping must be conducted to ensure that geotechnical and design parameters are confirmed and to ensure that appropriate action is taken to inform the Commission of design changes needed to accommodate actual field conditions encountered.	• Seepage monitoring (Section 4.2.1.1) • Drift inspection (Section 4.2.1.8) • Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Thermally accelerated drift in-drift environment monitoring (Section 4.2.1.11) • Subsurface mapping (Section 4.2.1.1) • Seismicity monitoring (Section 4.2.2.2) • Construction effects monitoring (Section 4.2.2.3) • Thermally accelerated drift thermal-mechanical monitoring (Section 4.2.2.4)
10 CFR 63.132(b)–Subsurface conditions must be monitored and evaluated against design assumptions.	• Seepage monitoring (Section 4.2.1.1) • Drift inspection (Section 4.2.1.8) • Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Thermally accelerated drift in-drift environment monitoring (Section 4.2.1.11) • Seismicity monitoring (Section 4.2.2.2) • Construction effects monitoring (Section 4.2.2.3) • Thermally accelerated drift thermal-mechanical monitoring (Section 4.2.2.4)
10 CFR 63.132(c)–Specific geotechnical and design parameters to be measured or observed, including any interactions between natural and engineered systems and components, must be identified in the *Performance Confirmation Plan* (SNL 2008a).	• Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Subsurface mapping (Section 4.2.2.2) • Construction effects monitoring (Section 4.2.2.3) • Thermally accelerated drift thermal-mechanical monitoring (Section 4.2.2.4)
10 CFR 63.132(d)–These measurements and observations must be compared with the original design bases and assumptions. If significant differences exist between the measurements and observations and the original design bases and assumptions, the need for modifications to the design or in construction methods must be determined and these differences, their significance to repository performance, and the recommended changes reported to the Commission.	• Evaluation of results and reporting (Section 4.1.3)
10 CFR 63.132(e)–In situ monitoring of the thermal-mechanical response of the underground facility must be conducted until permanent closure, to ensure that the performance of the geologic and engineering features is within design limits.	• Drift inspection (Section 4.2.1.8) • Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Thermally accelerated drift thermal-mechanical (Section 4.2.2.4)

Table 4-2. Relationship of Performance Confirmation Activities to 10 CFR 63, Subpart F, Requirements (Continued)

10 CFR 63, Subpart F	Performance Confirmation Activities
10 CFR 63.133(a)–During the early or developmental stages of construction, a program for testing of engineered systems and components used in the design, such as, for example, borehole and shaft seals, backfill, and drip shields, as well as the thermal interaction effects of the waste packages, backfill, drip shields, rock, and unsaturated zone and saturated zone water, must be conducted.	• Seepage monitoring (Section 4.2.1.1) • Thermally accelerated drift near-field monitoring (Section 4.2.1.9) • Construction effects monitoring (Section 4.2.2.3) • Thermally accelerated drift thermal-mechanical monitoring (Section 4.2.2.4) • Seal and backfill testing (Section 4.2.3.1)
10 CFR 63.133(b)–The testing must be initiated as early as practicable.	• Program objectives and overview (Section 4.1) • Design testing other than waste package (Section 4.2.3)
10 CFR 63.133(c)–If backfill is included in the repository design, a test must be conducted to evaluate the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.	• Seal and backfill testing (Section 4.2.3)
10 CFR 63.133(d)–Tests must be conducted to evaluate the effectiveness of borehole, shaft, and ramp seals before full-scale operation proceeds to seal boreholes, shafts, and ramps.	• Seal and backfill testing (Section 4.2.3.1)
10 CFR 63.134(a)–A program must be established at the geologic repository operations area for monitoring the condition of the waste packages. Waste packages chosen for the program must be representative of those to be emplaced in the underground facility.	• Dust buildup monitoring (Section 4.2.1.10) • Thermally accelerated drift in-drift environment monitoring (Section 4.2.1.11) • Waste package monitoring (Section 4.2.4.1)
10 CFR 63.134(b)–Consistent with safe operation at the geologic repository operations area, the environment of the waste packages selected for the waste package monitoring program must be representative of the environment in which the wastes are to be emplaced.	• Monitoring and testing of waste packages (Section 4.2.4)
10 CFR 63.134(c)–The waste package monitoring program must include laboratory experiments that focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the underground facility during the waste package monitoring program must be duplicated in the laboratory experiments.	• Corrosion testing (Section 4.2.4.2) • Corrosion testing of thermally accelerated drift samples (Section 4.2.4.3) • Waste form testing (Section 4.2.4.4)
10 CFR 63.134(d)–The waste package monitoring program must continue as long as practical up to the time of permanent closure.	• General requirements (Section 4.2.1) • Monitoring and testing of waste packages (Section 4.2.4)

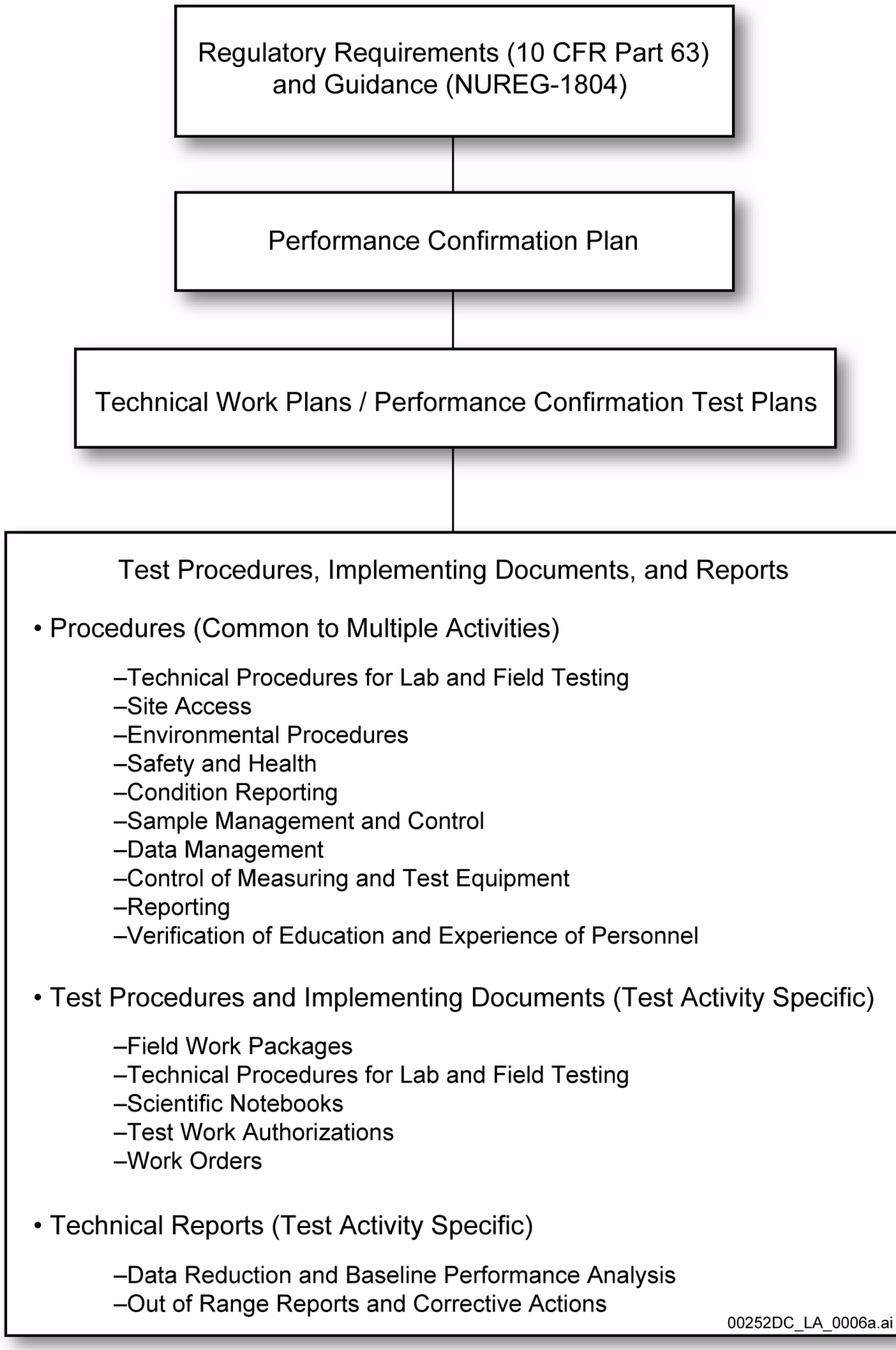

Figure 4-1. Planning and Procedural Document Hierarchy for Performance Confirmation Testing Implementation

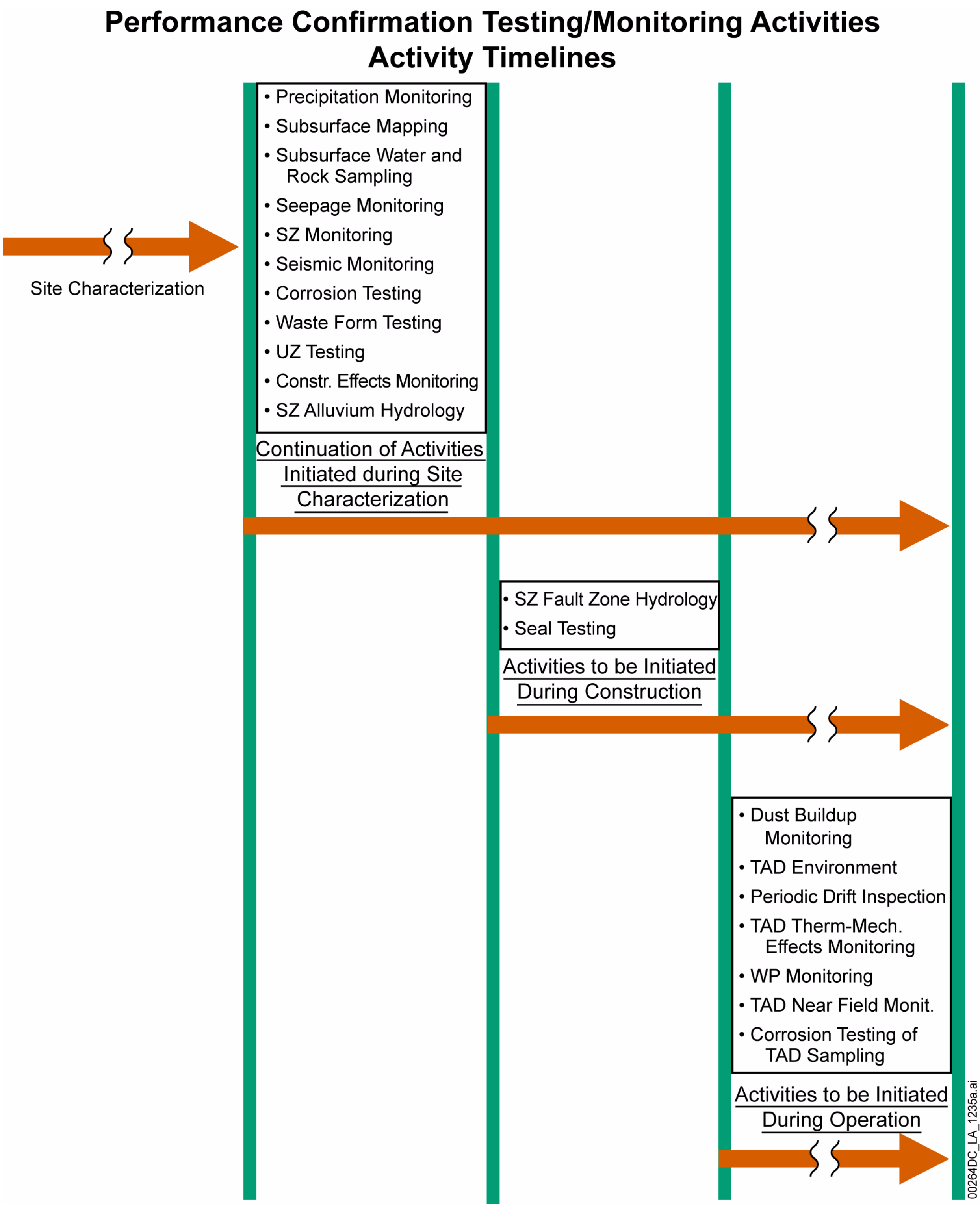

Figure 4-2. Schedule of Performance Confirmation

NOTE: SZ = saturated zone; TAD = transportation, aging, and disposal; UZ = unsaturated zone; WP = waste package.

Source: SNL 2008a.