DOC.20080227.0003

QA: QA

TDR-PCS-SE-000001 REV 05

November 2004

BECHTEL SAIC COMPANY LLC

Performance Confirmation Plan

THIS DOCUMENT CONTAINS THE FOLLOWING, LOCATED AT THE BACK OF THE DOCUMENT:
1) ADDENDUM 001, DATED 02/25/2008

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
1551 Hillshire Drive
Las Vegas, Nevada 89134-6321

Prepared by:
Bechtel SAIC Company, LLC
1180 Town Center Drive
Las Vegas, Nevada 89144

Under Contract Number
DE-AC28-01RW12101

DISCLAIMER

Originator:

R.J. Henning
Post Closure Activities Staff

Date 11/18/2004

Revision Manager:

D.J. Weaver
Test Coordination Office Manager

Date 11/18/04

Checker:

R.A. Wagner
Total System Performance Assessment Staff

Date 18 Nov 04

Quality Engineer Representative:

S.R. Dana
Quality Engineering Supervisor

Date 11/19/04

Responsible Manager:

W.W. Watson
Post Closure Activities Deputy Manager

Date 11/22/04

INTENTIONALLY LEFT BLANK

CHANGE HISTORY

Revision Number	Interim Change No.	Date of Revision	Description of Change
00		09/21/1997	Initial issue of Plan issued as Report No. B00000000-00841-4600-00002; this version served as basis for Viability Assessment Report.
01		03/20/2000	Extensive revision of plan to incorporate revised repository configuration and revised regulatory guidance; general approach and performance confirmation activities changed; parameter sheets deleted. This version is basis for Site Recommendation report. This revision supersedes prior plan, document No. B00000000-00841-4600-00002.
01	1	05/20/2000	Revision of the plan to address additional comments. Minor text changes in all chapters to accurately reflect current program context. Figure 5-1 was revised to clarify the inspection gantry's capabilities. Text in Tables E-5 and E-6 were updated to reflect recent revision of the Monitored Geologic Repository Project Description Document, TDR-MGR-SE-000004. Table E-7 was deleted due to changing program requirements. Reference added to Table D-1 to provide source for pallet description.
01	2	01/30/2002	Revision of the plan was initiated to address changes in requirements documents (including the Yucca Mountain Site Characterization Project Requirements Document and Monitored Geologic Repository Project Description Document), and to incorporate the issuance of the final version of 40 CFR Part 197. These changes are reflected in revisions to Chapters 1, 3, and 9, and Appendix E. In addition, Chapter 3 was revised to reflect revision 4 of the Repository Safety Strategy: Plan to Prepare the Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations.

CHANGE HISTORY (Continued)

Revision Number	Interim Change No.	Date of Revision	Description of Change
01 (cont'd)	2	01/30/2002	Revision of Appendix D and inclusion of a new appendix (Appendix H) were made to support design flexibility of the repository over a range of thermal operating modes, and to clarify the use of the higher-temperature operating mode in developing this version of the plan. Appendix E was revised to include an evaluation of the final version of 10 CFR 63, and indicates areas for update in the next revision of the plan. The definitions of test categories in Appendix F were revised to reflect the revision of the Monitored Geologic Repository Test and Evaluation Plan. In addition, minor changes were made throughout the document to update citations and cross-references.
02		07/01/2003	Complete rewrite to incorporate revised performance confirmation program based on guidance in the Yucca Mountain Review Plan, Final Report and 10 CFR Part 63. Documents decision analysis to rescope the program. Change includes basing the performance confirmation program on the nine barriers documented for the site recommendation, rather than the principal factors documented in the Viability Assessment.
02	01	10/16/2003	Incorporate ORD deliverable acceptance review comments addressing clarity and policy.
02	02	11/21/2003	Improve consistency within the document.
03		04/13/2004	Revised and rewritten to more closely reflect the scope and level of detail necessary and sufficient for regulatory compliance in the License Application.

CHANGE HISTORY (Continued)

Revision Number	Interim Change No.	Date of Revision	Description of Change
04		08/25/2004	Revised and rewritten to incorporate comments received in the Review Coordination Rejected Deliverable Transmittal, (Mitchell 2004, [DIRS 170504] Enclosure 2). Specifically this revision, addresses the requirements of the *Yucca Mountain Review Plan, Final Report* (NRC 2004 [DIRS 163274]), describes in more detail how the program will be implemented, provides a more detailed discussion of why the activities were chosen, acknowledges that the plan began during site characterization and describes how it will be transitioned to the future. Change bars are not used.
05	0	11/22/2004	Document changed to address acceptance conditions identified in accordance with AP-7.5Q, *Submittal, Review, and Acceptance of Deliverables*, [DIRS 172197] from a review of Rev. 04. Specifically, changes were made to add a discussion of the assessment conducted to evaluate if the activities are consistent with the results of Total System Performance Assessment for the License Application, clarify the role and function of the integration group, clarify the condition limits and U.S. Nuclear Regulatory Commission notification discussed in Section 4, and to correct minor editorial issues. Change bars in the margin indicate text, figures, and tables that have been changed.

INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENTS

The performance confirmation program has been evolving for many years. It is important to acknowledge the contributions of the following major contributors during the evolution of the performance confirmation program. Order of presentation is alphabetical, not based on effort. Major contributors to the initial issue of the *Performance Confirmation Plan* include: A. Brandstetter, K.M. Kersch, D.A. McAffee, J.K. McCoy, R.D. McCright, D.G. McKenzie, M.T. Peters, T.R. Scotese, and B.H. Thomson. Major contributors to Revision 01 include: S. Ballard, J.O. Duguid, J. Jessen, D.S. Kessel, E.N. Lindner, K. MacNeil, M.J. Mrugala, M.T. Peters, M.D. Sellers, M.B. Skorska, D. Stahl, B.H. Thomson, C.F. Vecchione, and R.M. Wilson. Major contributors to the preparation of Revision 02 and to the initial development stages of Revision 03 include: S.C. Beason, J.F. Beesley, J.A. Blink, V. Chipman, L. Concors, J.O. Duguid, S.W. Goodin, S. Hommel, K.E. Jenni, G.D. LeCain, W. Lin, R.D. McCright, A.M. Monib, T.L. Neiman, R.D. Snell, and R.A. Wagner. Authors of Revision 03 include: A.J. Smith, and R.D. Snell. Major contributors to this Revision 04 include: R.J. Henning, A.J. Smith, R.D. Snell, and D.J. Weaver. During the development of the *Performance Confirmation Plan*, DOE Technical Management has been provided by D.L. Barr, W.J. Boyle, E.T. Smistad, and M.C. Tynan.

INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

This *Performance Confirmation Plan* describes the U.S. Department of Energy strategy to collect, evaluate, and report on data used to confirm the basis for estimates of repository performance and preservation of the ability to retrieve spent nuclear fuel and high-level radioactive waste from the repository at Yucca Mountain, Nevada. A repository performance confirmation program has been developed that is directed at evaluating the adequacy of the information used to demonstrate compliance with the performance objectives in 10 CFR Part 63, Subpart E (10 CFR 63.2). A description of the performance confirmation program is required in the Safety Analysis Report as part of the License Application (10 CFR 63.21(c)(17)).

Regulatory requirements for the performance confirmation program are specified in 10 CFR Part 63, Subpart F. Guidance for the program is also provided in the *Yucca Mountain Review Plan, Final Report*, (NUREG-1804). The performance confirmation program began during site characterization and will continue until permanent closure of the repository (10 CFR 63.131(b)). The scope of the program consists of tests, monitoring activities, and analyses to evaluate the adequacy of assumptions, data, and analyses that lead to the findings that permitted construction of the repository and subsequent emplacement of wastes (10 CFR 63.102(m)).

The U.S. Nuclear Regulatory Commission requires that the performance confirmation program for the repository confirm that the actual subsurface conditions encountered and changes in these conditions during construction and waste emplacement operations are within the limits assumed in the licensing review (10 CFR 63.131(a)(1)). The performance confirmation program is also required to indicate, where practicable, whether the natural and engineered systems and components designed or assumed to operate as barriers after permanent closure are functioning as intended and anticipated (10 CFR 63.131(a)(2)). The performance confirmation program is designed to address uncertainties inherent in the reliance on performance assessment for estimating performance, and to increase confidence that performance objectives designed to protect public health and safety are satisfied. Direct observations and measurements during the preclosure period are planned to achieve these goals.

The purpose and objectives of this *Performance Confirmation Plan*, as quoted in regulation 10 CFR 63.102(m) is that:

> a performance confirmation program be conducted to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Key geotechnical and design parameters, including any interactions between natural and engineered systems and components, will be monitored throughout site characterization, construction, emplacement, and operation to identify any significant changes in the conditions assumed in the license application that may affect compliance with the performance objectives specified at 63.113(b) and (c).

In summary, key requirements of the regulation state that the performance confirmation program must:

- Confirm that subsurface conditions, geotechnical and design parameters are as anticipated and that changes to these parameters are within limits assumed in the License Application.
- Confirm that the waste retrieval option is preserved.
- Evaluate information used to assess whether natural and engineered barriers function as intended.
- Evaluate effectiveness of design features intended to perform a postclosure function during repository operation and development.
- Monitor waste package condition.

The repository system is composed of two natural barriers and one Engineered Barrier System that have been characterized and designed to work together to prevent or reduce the movement of water or radionuclides, or prevent the release or substantially reduce the release rate of radionuclides. The features and structures, systems, or components of the repository system that form these barriers include any feature or structure, system, or component that contributes to the performance of one of the three barriers and is considered to be important to waste isolation.

The location and elevation of the repository site take advantage of the characteristics of the geologic setting, in general, and of the repository host rock, the Topopah Spring welded tuff hydrogeologic unit, in particular. These characteristics include:

- A semiarid climate with limited precipitation.
- A thickness of rock and soil above the repository of at least 215 meters to nearly 365 meters.
- Hydrogeologic and geochemical characteristics that limit radionuclide movement.
- Geologic and geomechanical characteristics that permit the design and construction of an effective Engineered Barrier System.
- Geomechanical and thermal characteristics that allow maintenance of a stable facility with adequate capacity for waste disposal.
- Absence of significant faults within the disposal area.
- Depth to groundwater below repository emplacement drifts from more than 250 to nearly 400 meters.

The robustness of the Yucca Mountain engineered and natural system reduces the possibility that uncertainties associated with any one parameter could result in conditions that would lead to exceeding the postclosure performance objectives for individual protection (10 CFR 63.311) and groundwater protection (10 CFR 63.331), or result in conditions that would preclude retrieval of the waste (10 CFR 63.111(e). By examining the confidence and accuracy in understanding subsystem components, as well as the overall system sensitivity to particular features, the resulting performance confirmation program is directed at confirming design and model parameters and consequently the bases for predictions of long-term performance and for the demonstration that repository conditions will not preclude preservation of the retrievability option. This *Performance Confirmation Plan* provides a description of the program designed to meet the above listed requirements.

A methodical approach has been used in developing the performance confirmation program. The eight stages of the approach are as follows:

1. Select performance confirmation parameters and test methods
2. Predict performance and establish a baseline
3. Establish bounds and tolerances for key parameters
4. Establish test completion criteria and variance guidelines
5. Plan activities, and construct and install the performance confirmation program
6. Monitor, test, and collect data
7. Analyze and evaluate data
8. Recommend corrective action in the case of variance.

The eight stages of performance confirmation rely on the selection of parameters based on their importance to performance. The phased nature of repository construction and waste emplacement allows progressive development of performance confirmation approaches. Monitoring and test methodologies for activities continuing from site characterization are more fully developed, construction period activities require finalization, and operational period activities are mostly at the conceptual stage of planning. Future revisions of this *Performance Confirmation Plan* will provide additional details and more complete discussions in the various stages of the approach.

The approach to the program is risk-informed, performance-based, focusing on parameters and processes that are important to evaluating assumptions, data and analyses used in the licensing basis. Generally, parameters that are important to either system performance or barrier capability, and have a relatively high degree of uncertainty, would be considered a valuable activity to include in the performance confirmation program. The program must be linked to the performance assessment used for the License Application to provide the basis to evaluate whether the program is reasonable and complete, which means these assessments have to be maintained during performance confirmation, and that the *Performance Confirmation Plan* will be revised periodically based on new or revised analyses. Performance confirmation monitoring is designed to focus on areas important to evaluating information supporting assessments of repository performance relative to the regulatory postclosure objectives or where uncertainties in the performance assessments result in high potential risk. Therefore, this risk-informed, performance-based program allocates resources to those areas that are most important for performance, thus providing the greatest support for future decisions.

The approach used for selecting the set of activities (measured parameters and data acquisition methods) for evaluating the postclosure performance of the repository was based on three criteria and a decision analysis process, incorporating the definition of risk, applied to a set of parameters identified by subject matter experts.

- How important is the parameter to barrier capability and system performance?
- What is the level of confidence in the current knowledge about the parameter?
- How accurately can information be obtained by a particular test activity?

Performance confirmation began during the characterization of the Yucca Mountain site and will continue during repository construction and through operational emplacement of waste, only concluding when repository closure is licensed. Performance confirmation tests that will continue from activities that were performed as a part of site characterization, with appropriately modified work scopes, are as follows:

- Precipitation monitoring (precipitation quantities and composition measured at the Yucca Mountain site

- Seepage monitoring (seepage monitoring and analysis in alcoves on the repository intake side and in repository thermally accelerated drifts)

- Subsurface water and rock testing (chloride mass balance and isotope chemistry analysis of water samples collected at selected underground locations)

- Unsaturated zone testing (field-testing of transport and sorptive properties of unsaturated zone rock in an ambient seepage alcove or a drift with no waste packages emplaced)

- Saturated zone monitoring (measurements of water level, electrochemical potential, hydrogen potential, and background radionuclide concentrations in saturated zone wells at the repository site and in Nye County)

- Saturated zone alluvium testing (tracer testing of alluvium transport properties in the Alluvial Test Complex)

- Subsurface mapping (mapping of fractures, faults, stratigraphic contacts and lithophysal characteristics of rock in the underground openings)

- Seismicity monitoring (monitoring of regional seismic activity and observation of fault displacements following significant seismic events)

- Construction effect monitoring (measurement of construction deformation of underground openings/confirmation of related rock mechanical properties)

- Corrosion testing (laboratory samples testing of waste package, waste package pallet, and drip shield materials corrosion behavior in the range of expected repository environments)

- Waste form testing (laboratory testing of waste form dissolution and waste package coupled effects including use of scale mockups of waste package).

New activities that will begin during construction or operations phases include:

- Saturated zone fault zone hydrology testing (hydraulic and tracer testing in fault zones).

- Drift inspection (periodic inspection of emplacement drifts and thermally accelerated drifts using remote inspection and measurement techniques).

- Thermally accelerated drift near-field monitoring (monitoring of rock mass and water properties in the near-field of a thermally accelerated emplacement drift).

- Dust buildup monitoring (monitoring and laboratory evaluations of quantity and composition of dust on engineered barrier surfaces and samples).

- Thermally accelerated drift environment monitoring (monitoring and laboratory evaluations of environmental conditions in a thermally accelerated drift including gas and water compositions, temperatures, film depositions, microbes, radiation and radiolysis effects using remote techniques).

- Thermally accelerated drift thermal-mechanical effects monitoring (monitoring of drift and invert degradation in a thermally accelerated drift).

- Seal testing (testing of effectiveness of borehole seals in the laboratory, shaft and ramp seals in the field, and backfill emplacement techniques).

- Waste package monitoring (monitoring of integrity of waste packages using visual inspection and/or internal pressure measurement employing remote monitoring techniques).

- Corrosion testing of thermally accelerated drift samples (laboratory testing of waste package, waste package pallet, and drip shield samples obtained from the thermally accelerated drift).

Each activity selected may combine one or more parameters that relate to a specific feature of barrier capability, total system performance, or the regulatory requirements. The barriers include the Upper and Lower Natural Barriers, and Engineered Barrier System. Some activities support evaluation of preservation of the ability to retrieve waste, or disruptive events parameter confirmation. Each activity is presented using subheadings listed below:

- **Activity Description** (which lists the major parameters that may be measured or tested, the barrier that the activity investigates, when testing and monitoring began or are anticipated to begin, and other programs that may support interpretations)
- **Purpose** (The purpose of the test activity)
- **Selection Justification** (both technical and regulatory)
- **Current Understanding** (what is known about the parameters covered by this activity, including the baseline information)
- **Anticipated Methodology** (that may be appropriate to test and monitor parameters in that activity, typical data evaluation, and an evaluation of potential adverse impacts as a result of this activity).

The activities will be planned, using technical work plans and products known as performance confirmation test plans, to be developed later (as described in Sections 5 and 6). The performance confirmation test plans will be implemented using field work packages, technical procedures, scientific notebooks, and a process of work orders and test work authorization for field work. Schedules for implementation are described in the individual activity descriptions and a section on schedule.

The performance confirmation testing and monitoring activities will be planned and implemented in accordance with appropriate technical, safety, environmental, and quality procedures in a manner comparable to that applied during the site characterization phase of the Yucca Mountain Project. However, there are some essential distinctions in planning and implementation. The planning process for performance confirmation activities will be adapted to be directly applicable to performance confirmation, by identifying baseline information, variance criteria, and the process followed if the measurements are outside the preestablished expectations, including the U.S. Nuclear Regulatory Commission notification criteria. In addition, special emphasis will be given to instrumentation selection, maintenance, reliability, and calibration considering many of these tests will be in locations not easily accessible or conducted over long periods of time. Each activity will be evaluated to assess relevance to: worker safety; waste isolation impacts due to test construction, performance confirmation activities or both; potential interactions between independent activities; and potential interactions between repository construction activities and performance confirmation activities. Performance confirmation test plans will be the primary planning document for each test activity, being implemented by subordinate implementing and work control documents.

The *Performance Confirmation Plan* is a planning document and as such, the levels of citation and reference for statements of accepted project knowledge are commensurate with planning document format. Each of the refinements and evaluations of the activities used a number of criteria, including applying the latest technical information available. This has resulted in a performance confirmation program that is consistent with the licensing case.

The performance confirmation program was initially based on the in-process understanding of performance and barrier capability developed prior to completing the Total System Performance Assessment for the License Application. Recently, an evaluation of performance confirmation testing relevance to the Total System Performance Assessment for the License Application was conducted (Watson 2004 [DIRS 172213]). This revision addresses the appropriateness of the proposed performance confirmation testing relative to Total System Performance Assessment for the License Application.

The review by the Total System Performance Assessment group concluded that no new performance confirmation activities were required. Clarifications to the purpose and modifications to the anticipated methodology for waste form testing better confirm igneous scenario assumptions. These clarifications of scope of this existing activity support the technical basis for performance confirmation for the assessment of total system performance for the igneous intrusion scenario.

The next *Performance Confirmation Plan* revision will perform a check against the License Application performance assessment using the model input database and sensitivity evaluations to confirm that the performance confirmation activities are appropriate. Both the nominal and disruptive performance assessment scenarios will be evaluated during this assessment to ascertain whether any additional activities should be added to the Plan. During detailed test planning, pretest predictions and calculations will be performed, controlled, and referenced within the individual performance confirmation test plans.

The *Performance Confirmation Plan* provides the current description of the Yucca Mountain performance confirmation program. Section 1 of this document provides an introduction, purpose and objectives, a description of the approach used to select the parameters and test methods, identification of the barriers, a discussion on waste retrievability, a description of how the performance confirmation program fits in context with other testing and monitoring programs at Yucca Mountain, and a discussion of quality assurance. Section 2 provides performance confirmation regulatory requirements and guidance. Section 3 provides a description of planned performance confirmation activities, proposed test methodologies, a description of current understanding, schedule for implementation, and a rationale (both technical and regulatory) for why the listed activities are important to performance confirmation of barrier capability or total system performance. Section 4 provides discussions of data management, analysis, and reporting strategies, with details on data and trending. Section 5 provides the experimental design strategies, implementation of the activities including test planning and technical procedure usage, and a list of ongoing activities with their ties to site characterization implementing documents. Section 6 provides an overall schedule for the program. Section 7 provides the references.

INTENTIONALLY LEFT BLANK

CONTENTS

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

INTENTIONALLY LEFT BLANK

FIGURES

Page

TABLES

Page

INTENTIONALLY LEFT BLANK

ACRONYMS AND ABBREVIATIONS

DOE	U.S. Department of Energy
ECRB	Enhanced Characterization of the Repository Block
Eh	electrochemical potential
ESF	Exploratory Studies Facility
K_d	sorption coefficient
MPBX	multi-point borehole extensometer
NRC	U.S. Nuclear Regulatory Commission
PC Test Plan	Performance Confirmation Test Plan
pH	hydrogen potential
SAR	Safety Analysis Report
SPBX	single-point borehole extensometer
SSCs	structures, systems, and components
TSPA	total system performance assessment
TSPA-LA	*Total System Performance Assessment for the License Application*
YMRP	*Yucca Mountain Review Plan, Final Report*

LITHOSTRATIGRAPHIC, HYDROGEOLOGIC, OR THERMAL-MECHANICAL UNITS

PTn	Paintbrush Tuff nonwelded hydrogeological unit
Tptp	Topopah Spring Tuff crystal-poor member
Tptpll	Topopah Spring Tuff crystal-poor lower lithophysal zone
Tptpmn	Topopah Spring Tuff middle nonlithophysal zone
TSw	Topopah Spring welded tuff hydrogeological unit

INTENTIONALLY LEFT BLANK

1. INTRODUCTION

1.1 BACKGROUND

This *Performance Confirmation Plan* describes the U.S. Department of Energy (DOE) strategy to collect, evaluate, and report on data used to confirm the basis for estimates of performance and preservation of the ability to retrieve spent nuclear fuel and high-level radioactive waste from the repository at Yucca Mountain, Nevada. The regulatory construct for permitting disposal of high-level radioactive wastes in a repository, codified in 10 CFR Part 63 *Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*[1], [DIRS 156605] emphasizes a risk-informed, performance-based approach directed at the performance of the disposal system. Performance confirmation is designed to address uncertainties inherent in the reliance on performance assessment for estimating performance and, to the extent possible, to increase confidence that performance objectives designed to protect public health and safety are satisfied. Observations and measurements during the preclosure period will be used achieve these goals.

Developing confidence that a repository will successfully isolate waste for the compliance period is challenging because of the long time frames and the inherent uncertainties that are involved. Therefore, the overall evaluation of repository postclosure is based on two fundamental and independent components: (1) a robust repository system involving multiple barriers, and (2) a thorough modeling of the repository that is based on multiple lines of evidence and that incorporates appropriate methods, models, and data.

Evaluating a first-of-a-kind facility like the repository requires that models be used to estimate system performance over the compliance period because direct observation and verification of this performance is not possible. As the licensee, DOE will provide the technical basis for the models used in the performance assessment on which permitting construction and subsequent receipt and possession will be based. Performance confirmation will provide data to verify the adequacy of the information presented in the license application as the basis for these U.S. Nuclear Regulatory Commission (NRC) decisions. In total, the elements of the repository postclosure performance work together to provide confidence that the system itself is robust and that the understanding of repository performance reflected in model results is appropriate. The performance confirmation program supports these objectives by providing information to confirm that (1) subsurface conditions are as expected, and (2) the behavior of repository system barriers is consistent with performance assessment results.

The supplementary information to the final rule, 10 CFR Part 63, reflects a similar view that performance confirmation is one element of the broad range of information the NRC will consider in arriving at its licensing decisions, and that performance confirmation is important to the consideration and treatment of uncertainties, and increasing confidence that the postclosure performance objectives are satisfied (66 FR 55732, [DIRS 156671] p. 55746).

---

[1] Because 10 CFR Part 63 is used so frequently in this document, the reference citation 10 CFR Part 63 *Energy: Disposal of High-Level Radioactive Wastes in a Geological Repository at Yucca Mountain, Nevada* ([DIRS 156605]) will only be repeated the first time it is referenced in each section.

Performance confirmation began during the characterization of the Yucca Mountain site and will continue during repository construction and through operational emplacement of waste, only concluding when repository closure is licensed. The monitoring and testing activities (an activity is a combination of a test parameter and a test method), which were performed as a part of site characterization and which will be continued, with appropriately modified work scopes, as a part of performance confirmation, are as follows:

- Precipitation monitoring
- Seepage monitoring
- Subsurface water and rock testing
- Unsaturated zone testing
- Saturated zone monitoring
- Saturated zone alluvium testing
- Subsurface mapping
- Seismicity monitoring
- Construction effect monitoring
- Corrosion testing
- Waste form testing.

New activities that will begin during construction or operations phases include:

- Saturated zone fault hydrology testing
- Drift inspection
- Thermally accelerated drift near-field monitoring
- Dust buildup monitoring
- Thermally accelerated drift environment monitoring
- Thermally accelerated drift thermal mechanical effects monitoring
- Seal testing
- Waste package monitoring
- Corrosion testing of thermally accelerated drift samples.

During the time from initiation of construction until repository closure, performance confirmation activities will include in situ monitoring and testing, as well as laboratory testing, to evaluate the adequacy of the information and assumptions that were the basis for postclosure performance predictions and for supporting the retrievability option.

During construction, activities will be directed at confirming subsurface conditions and changes anticipated during the excavation of the repository. With emplacement of wastes, activities will turn to confirming subsurface condition changes related to introduction of thermal loads, and evaluating assessments of the functionality of natural and engineered barriers important to waste isolation. Monitoring to confirm the preservation of the ability to retrieve wastes is a focus of performance confirmation during construction and operation. Several of the activities described in Section 3 (e.g., construction effects monitoring and drift inspection) confirm the preservation of the ability to retrieve waste.

The phased nature of repository development allows progressive development of performance confirmation approaches. Monitoring and test methodologies for activities continuing from site characterization are more thoroughly developed, while the planning for some construction period activities requires finalization, and operational period activities are mostly at the conceptual stage of planning.

1.2 PURPOSE AND OBJECTIVES OF THE PERFORMANCE CONFIRMATION PLAN AND PROGRAM

The purpose and objectives of this program, as stated in regulation 10 CFR 63.102(m) are that "a performance confirmation program will be conducted to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Key geotechnical and design parameters, including interactions between natural and engineered systems and components, will be monitored during site characterization, construction, emplacement, and operation to identify significant changes in the conditions assumed in the License Application that may affect compliance with the performance objectives specified at 10 CFR 63.113(b) and (c)." This *Performance Confirmation Plan* provides a description of the performance confirmation program.

To accomplish these objectives, the DOE has developed this *Performance Confirmation Plan* for the Yucca Mountain Repository that addresses the requirements of 10 CFR Part 63 Subpart F and the related acceptance criteria in Section 2.4.3 of the Yucca Mountain Review Plan (YMRP) NUREG-1804, (NRC 2003 [DIRS 163274]). The *Performance Confirmation Plan* addresses uncertainties within the performance assessments used for estimating performance, and is designed to increase confidence that the performance objectives designed to protect public health and safety are satisfied.

The use of this *Performance Confirmation Plan* is limited to activities necessary to support current DOE planning. Specific activities may evolve, as the performance confirmation program proceeds, and the *Performance Confirmation Plan* will be updated accordingly.

The performance confirmation testing and monitoring activities will be planned and implemented in accordance with appropriate technical, safety, environmental, and quality procedures in a manner comparable to that applied during the site characterization phase. However, there are some essential distinctions in the planning and implementation as described herein. The planning process for performance confirmation activities will be adapted to include information directly applicable to performance confirmation, including, baseline information, variance criteria, and the process followed if the measurements are outside the preestablished expectations, including the NRC notification criteria. In addition, special emphasis will be given to instrumentation selection, maintenance, reliability, and calibration considering many of these tests will be in locations not easily accessible or conducted over long periods of time. Each activity will be evaluated to assess relevance to worker safety, waste isolation impacts due to test construction, performance confirmation activities or both, potential interactions between independent activities, and potential interactions between repository construction activities and performance confirmation activities. Performance confirmation test plans will be the primary planning document for each test activity. Subordinate implementing and work control documents including field work packages, technical procedures, and work orders will be used to implement the activities.

1.3 PERFORMANCE CONFIRMATION PROGRAM SCOPE AND APPROACH

1.3.1 Risk-Informed, Performance-Based Program Approach

10 CFR Part 63 requires that the repository performance confirmation program evaluate information used to demonstrate that system and subsystem components operate as predicted. To facilitate this, activities for the performance confirmation program were selected using a risk-informed, performance-based approach. This approach focuses activities on aspects of the repository system that are relatively uncertain and could potentially have a significant effect on system or component performance.

An eight-stage approach has been used to develop the performance confirmation program (EPRI 2001 [DIRS 163435]). The eight stages of the approach are as follows:

1. Select performance confirmation parameters and test methods
2. Predict performance and establish a baseline
3. Establish bounds and tolerances for key parameters
4. Establish test completion criteria and variance guidelines
5. Plan activities, and construct and install the performance confirmation program
6. Monitor, test, and collect data
7. Analyze and evaluate data
8. Recommend corrective action in the case of variance.

The eight stages of the performance confirmation approach rely on the selection of parameters subject to testing based on the sensitivity to performance. The first stage of the approach has been substantially completed using a risk-informed, performance-based process, subject to changes due to new data and analyses (e.g., Total System Performance Assessment for the License Application (TSPA-LA)) and/or regulatory requirements arising out of the License Application review. Preliminary work, consistent with currently available performance assessment models and data, is underway on the second and third stages of the approach and is discussed in Section 4 of this Plan.

The *Performance Confirmation Plan* will be revised periodically based on proposed schedules (Section 6), comments resulting from the NRC review of the License Application, and changes in total system performance assessment (TSPA) evaluations. The emphasis of performance confirmation is on parameters related to barriers important to waste isolation. The definition of parameters related to barrier performance and repository performance environment rely on finalization of the postclosure safety evaluation supporting the License Application and the completion of sensitivity analyses directly related to barrier performance. The importance of the linkage to the final License Application postclosure barrier performance evaluation cannot be overemphasized.

Each of the refinements and evaluations of the activities used a number of criteria, including applying the latest technical information available. This has resulted in a performance confirmation program that is consistent with the licensing case.

Evaluation of Performance Confirmation Testing Relevance to TSPA-LA

The performance confirmation program was based on the in-process understanding of performance and barrier capability developed prior to completing the TSPA-LA. An evaluation of Performance Confirmation testing relevance to TSPA-LA was conducted (Watson 2004 [DIRS 172213]). This revision addresses the appropriateness of the proposed Performance Confirmation testing relative to the TSPA-LA.

The Performance Assessment group and the Performance Confirmation group assessed the relationships between the TSPA-LA and the 20 activities identified in the Performance Confirmation Plan. The assessment activity included interviewing cognizant Performance Assessment staff with an understanding of the TSPA-LA model report. The assessment resulted in a report approved by both the Performance Assessment and Performance Confirmation organizations (Watson 2004 [DIRS 172213]).

The results of the assessment affirmed that 17 of the 20 performance confirmation activities are the most directly relevant to the technical basis for postclosure performance assessment of the natural and engineered barriers ranging from medium to high importance or uncertainty to the TSPA-LA. The 17 performance confirmation activities that relate directly or indirectly (because they deal with information considered in process models) include:

- Corrosion testing
- Corrosion testing of thermally accelerated drift samples
- Dust buildup monitoring
- Precipitation monitoring
- Saturated zone alluvium testing
- Saturated zone fault hydrology testing
- Saturated zone monitoring
- Seal testing
- Seepage monitoring
- Seismicity monitoring
- Subsurface water and rock testing
- Subsurface mapping
- Thermally accelerated drift environment monitoring
- Thermally accelerated drift near-field monitoring
- Unsaturated zone testing
- Waste form testing
- Waste package monitoring.

The remaining three activities (Construction Effects Monitoring, Drift Inspection, and Thermally Accelerated Drift Thermal-Mechanical Monitoring) are related to the assessment of conditions that support the retrievability option and may provide information to assess the general framework for model development.

The evaluation of the changes to the TSPA-LA from the previous version used for *Total System Performance Assessment for Site Recommendation* and the *Risk Information To Support Prioritization Of Performance Assessment Models* was the basis for the initial risk informed, performance-based selection of the performance confirmation activities. This evaluation did result in a few possible enhancements or clarifications of the scope of performance confirmation activities that may have merit in supporting the technical basis for the current TSPA (Watson 2004 [DIRS 172213]).

Specifically, it was not evident, with the detail presented at this time in the *Performance Confirmation Plan*, if the igneous intrusion modeling case was addressed for the relevant subsystem features and processes that are important in modeling total system performance. These features and processes include:

- Sorption of some radionuclides on stationary phases (attachment to non-mobile materials)
- In-package radionuclide solubility
- In-package diffusion characteristics.

The review concluded that no new performance confirmation activities were required. Clarifications to the purpose and modifications to the anticipated methodology for waste form testing now better confirm igneous scenario assumptions. These clarifications of scope of this existing activity support the technical basis for performance confirmation for the assessment of total system performance for the igneous intrusion scenario.

DOE has authorized BSC to make improvements and refinements in the technical bases that support the Safety Analysis Report (SAR) (Hamilton-Ray 2004 [DIRS 172321]). Part of that scope is to evaluate disruptive igneous consequence modeling related to waste package damage by an igneous intrusion and waste form pulverization by an igneous eruption and make model changes as warranted. Currently, the igneous intrusion scenario includes potential changes in water chemistry that may result from contact with basalt rather than the other rock types in Yucca Mountain. If the results from these improvements suggest that the testing is still warranted, the potential for damage to waste form resulting from these conditions may be confirmed by enhanced testing in the waste form testing activity. If the improvements and refinements in the technical bases indicate that the waste package remains intact, then no additional testing would be necessary in waste form testing to confirm the improved TSPA results.

The next assessment will use the approved TSPA-LA model report, model input database, and sensitivity evaluations focused on performance confirmation to confirm that the activities included in the *Performance Confirmation Plan* are appropriate. Both the nominal and disruptive performance assessment scenarios will be evaluated during this assessment to ascertain whether any additional activities should be added to the plan.

1.3.2 Identification of Barriers

The repository system is composed of two natural barriers and one Engineered Barrier System that have been characterized and designed to work together to prevent or reduce the movement of water or radionuclides, or prevent the release or substantially reduce the release rate of radionuclides. These three barriers (with their corresponding features and structures, systems, and components [SSCs]) include individual natural features and Engineered Barrier System components that contribute to the performance of one of the three barriers and are considered to be important to waste isolation.

The three barriers (see Figure 1-1) are:

- Upper Natural Barrier
  - Topography
  - Soils
  - Unsaturated zone of rock (which includes the repository horizon).
- Engineered Barrier System
  - Waste forms
  - Cladding
  - Waste packages
  - Waste package pallets
  - Drip shields
  - Emplacement drift inverts
  - Emplacement drifts
  - Emplacement drift closures.
- Lower Natural Barrier
  - Unsaturated zone rock below the drifts
  - Saturated zone (consisting of rock and alluvium).

A detailed discussion of how the performance confirmation activities address these location based barriers, a discussion on thermally accelerated drifts (which involve both natural and engineered barrier features), and activities associated with disruptive events and the waste form itself are contained in Section 3.2 of this plan.

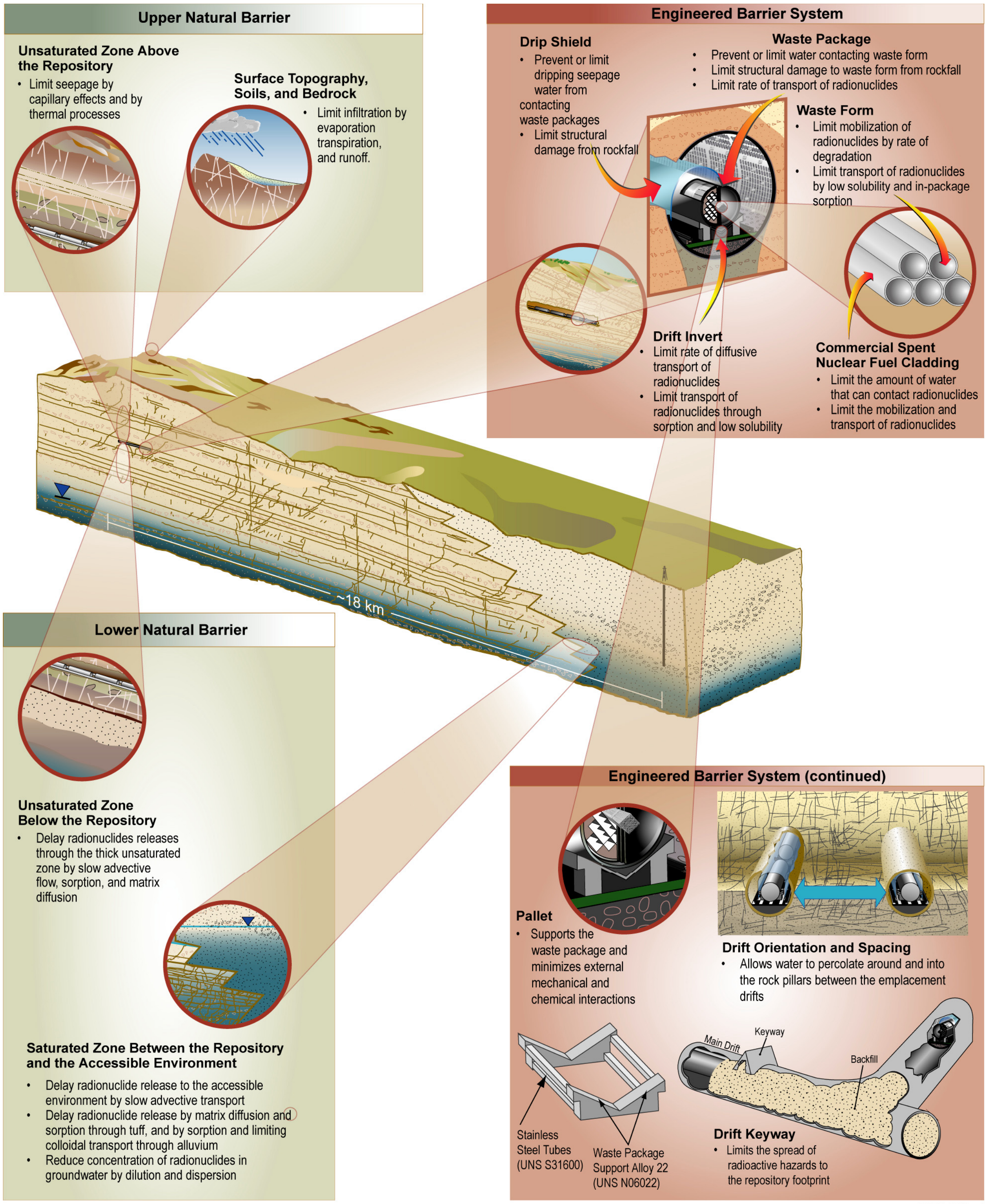


Figure 1-1. Schematic Diagram of the Repository

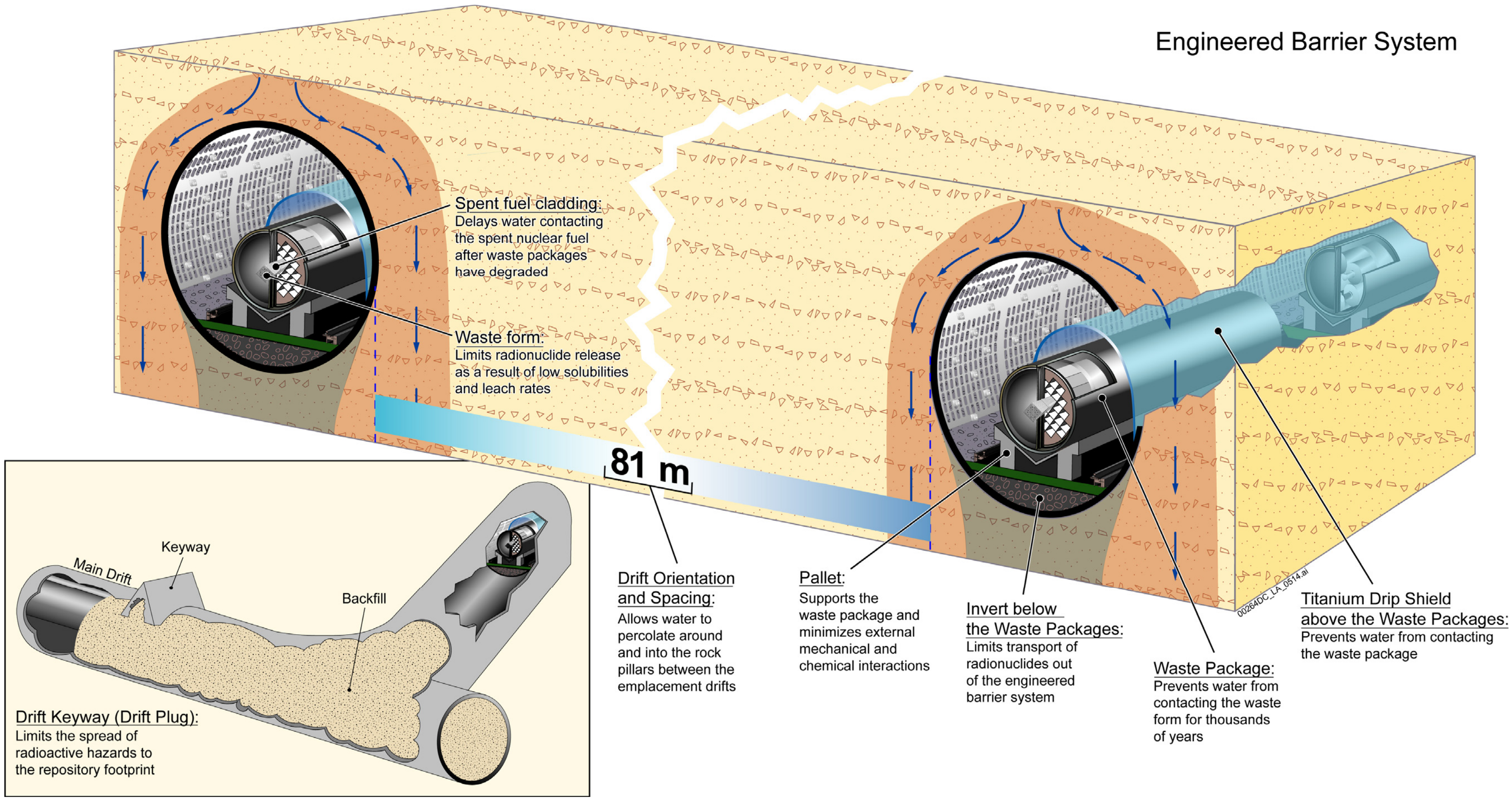


Figure 1-2. Schematic of the Engineered Barrier

1.4 PERFORMANCE CONFIRMATION PROGRAM ACTIVITIES

1.4.1 Activity Selection Approach

The approach for selecting the 20 activities (described in Section 3) uses risk insights to focus attention on issues important to public health and safety. Three primary questions ("What can go wrong?" "How likely is it?" and "What are the consequences?") embrace the traditional definition of risk, that is, probability multiplied by consequences. For the repository postclosure system, the risk is usually expressed in terms of probability-weighted annual dose, for comparison to the annual dose-based individual protection standard (NRC 2004 [DIRS 170243]).

Therefore, the approach used for selecting the set of activities (test parameters and test methods) to confirm postclosure performance of the repository was based on the following three criteria applied to a set of parameters identified by subject matter experts.

- How sensitive is barrier capability and system performance to the parameter?
- What is the level of confidence in the current knowledge about the parameter?
- How accurately can information be obtained by a particular test activity?

The first criterion above relates to the sensitivity of the total system performance and barrier capability to a performance confirmation parameter. The second criterion relates to confidence in the current representation of the parameter being measured or modeled. The less confidence in a particular parameter, the more important it becomes and the more it should be included in performance confirmation. The last of the criterion recognizes that it is not always possible to take direct measurements of a parameter, or that the difficulty in measuring a particular parameter is prohibitive so the accuracy and ease with which information can be collected is the third criterion to consider. To structure a program that addresses these criteria, a decision analysis approach was employed.

The cost of measuring the parameter was also identified as an applicable criterion, but was developed separately from the three criteria above that contribute to the value of including an activity. Overall, cost was a minor consideration in the development of the *Performance Confirmation Plan*. Generally, the lowest life-cycle cost alternative was chosen from viable options.

In contrast, an activity that would result in less accurate measurement of a parameter to which neither system performance nor barrier capability is sensitive, and for which there is high confidence in the current representation of that parameter would be considered a much lower utility activity to include in the performance confirmation program. For example, investigating solubilities of very short-lived radionuclides has a much lower utility because decay occurs so quickly that the radionuclides would not even incrementally impact the annual dose at the receptor.

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, together with methods of data acquisition. The subject matter experts identified over 300 activities, parameters, and data acquisition methods. Each combination of parameter and data acquisition method, termed an activity, was assigned a unique numeric identifier. A complete listing is provided in previous revisions to this plan. The activities were then evaluated by technical and subject matter experts as to 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.

The decision analysis approach offered three key benefits in evaluating candidate activities. This approach:

- Logically accounts for multiple objectives for the performance confirmation program
- Incorporates information from project personnel with different areas of expertise relevant to the selection of activities
- Provides a traceable and defensible logic for the performance confirmation activity selection.

The approach explicitly recognizes that both technical judgments and value judgments are a necessary part of decision-making, and that different people may be responsible for the different sets of judgments (Keeney and Raiffa 1976 [DIRS 157634]). Generally:

- Value judgments represent management decisions about what is important. In this analysis, value judgments included defining the objectives and criteria against which each of the candidate activities were to be evaluated and compared. Value judgments also included specifying the relative importance of each criterion. The value judgments in this analysis were provided by performance assessment management.
- Technical judgments represent input about how well various options meet the criteria defined by management. In this analysis, technical judgments included defining the candidate parameters and the proposed data acquisition methods. Technical judgments also included evaluations of how well each candidate activity meets the criteria defined by the performance assessment management team. These judgments were provided by project technical investigators familiar with each technical area.
- The overall utility of including a candidate activity is a function of both types of judgments: it depends on how well the activity meets the evaluation criteria, and the relative importance assigned to meeting each criterion.

The decision analysis approach to activity selection was conducted in three phases. In the first phase, candidate performance confirmation activities were identified and evaluated for inclusion in the performance confirmation program. In the second phase, the activity evaluations were used in combination with some general guidelines to develop candidate sets, (complete sets of activities that could form the basis for the performance confirmation program). The candidate sets were evaluated and compared based on a number of set-level criteria. In the third phase, Project management and senior advisors reviewed the candidate sets, selected a base set, and directed modifications to increase the robustness of that set.

Following the third phase, an additional series of refinement and evaluations through management and key technical representative reviews were conducted to bring activities listed in previous revisions of the Plan into closer alignment with plans for the License Application. This iterative process, beginning in the fall of 2003, reevaluated the list of activities based on the following criteria:

- Does the importance of the feature still merit consideration for the performance confirmation program?
- Can the activity be more appropriately classified as a technical specification?
- Can the activity be more appropriately classified as a model improvement?
- Has additional technical information from technical organizations become available that may impact a previous decision?
- Does the benefit of the activity justify its cost?
- Has the NRC or the DOE provided any alternative regulatory interpretations that make an activity irrelevant?
- Can the activity be more logically combined with any other activity based on the similarity in the data being gathered?
- Is the objective of the activity covered by another activity?
- Can the activity be reduced in scope and still obtain necessary information?

These evaluations later culminated in a series of meetings where Project management and key technical representatives reviewed the refinements, drawing a distinction among activities that were more commonly recognized as technical or design specifications, activities that were necessary for licensing defense, and activities that were required to confirm predictions of long-term performance (see Section 1.6 for a description of other project testing and monitoring programs).

The management and key technical representative evaluations resulted in related activities being consolidated where appropriate. Activities that did not strongly support regulatory compliance or the assessment of repository performance were deleted from the program (although they may be considered for other testing areas within the DOE further described in Section 1.6), while a few activities were added to reinforce regulatory compliance. The result of these is the current list of 20 test activities (including consolidated activities). These activities are described in detail, with explicit discussion on regulatory and technical selection criteria, in Section 3 (description of activities) of this plan.

1.4.2 List of Performance Confirmation Activities

Table 1-1 provides a listing of the 20 activities included in the performance confirmation program. The activities are grouped into the four acceptance criteria categories identified in the Section 2.4.3 of YMRP NUREG-1804, (NRC 2003 [DIRS 163274]) and are listed below under the sections that they principally support. A brief description of each activity, and the barrier which each activity addresses, is provided. More detailed activity descriptions are given in the individual activity description in Section 3.

Table 1-1. Testing and Monitoring Activities Included in the Performance Confirmation Program

ACTIVITY TITLE	ID #	ACTIVITY DESCRIPTION	BARRIER or PROCESS
1. YMRP GENERAL REQUIREMENTS TESTING AND MONITORING (NATURAL AND ENGINEERED BARRIERS)			
Precipitation monitoring	84	Monitoring of precipitation and composition analysis.	Upper Natural Barrier
Seepage monitoring	133	Seepage monitoring and laboratory analysis of water samples (from bulkheaded alcoves on the intake side of the repository and in thermally accelerated drifts).	Upper Natural Barrier
Subsurface water and rock testing	119	Laboratory analysis of chloride mass balance and isotope chemistry based on samples taken at selected locations of the underground facility.	Upper and Lower Natural Barriers
Unsaturated zone testing	137	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.	Upper and Lower Natural Barriers
Saturated zone monitoring	150	Monitoring of water level and hydrochemical sampling of the saturated zone upgradient, beneath and downgradient of Yucca Mountain.	Lower Natural Barrier
Saturated zone fault hydrology testing	159	Hydraulic and tracer testing of fault zone hydrologic characteristics, including anisotropy, in the saturated zone.	Lower Natural Barrier
Saturated zone alluvium testing	225	Tracer testing at the Alluvial Test Complex using multiple boreholes measuring parameters in the alluvium.	Lower Natural Barrier
Drift inspection	59	Regular inspection of nonemplacement drifts and periodic inspection of emplacement drifts, thermally accelerated drifts, and other underground openings using remote measurement techniques, as appropriate.	Engineered Barrier System, Retrievability
Thermally accelerated drift near-field monitoring	125	Monitoring of near-field coupled processes (thermal-hydrologic-mechanical-chemical) properties and parameters associated with the thermally accelerated drifts.	Upper and Lower Natural Barriers
Dust buildup monitoring	52	Monitoring and laboratory testing of quantity and composition of dust on engineered barrier surfaces.	Engineered Barrier System
Thermally accelerated drift in-drift environment monitoring	54	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 a thermally accelerated drift.	Engineered Barrier System

Table 1-1. Testing and Monitoring Activities Included in the Performance Confirmation Program (Continued)

ACTIVITY TITLE	ID #	ACTIVITY DESCRIPTION	BARRIER or PROCESS
2. GEOTECHNICAL AND DESIGN MONITORING AND TESTING			
Subsurface mapping	105	Mapping of fractures, faults, stratigraphic contacts, and lithophysal characteristics.	Upper and Lower Natural Barriers
ACTIVITY TITLE	**ID #**	**ACTIVITY DESCRIPTION**	**BARRIER or PROCESS**
Seismicity monitoring	167	Monitoring regional seismic activity. Observation of subsurface and surface (large magnitude) fault displacement after significant local or regional seismic events.	Disruptive Event, Retrievability
Construction effects monitoring	224	Monitoring construction deformation to confirm mechanical properties.	Upper Natural Barrier, Retrievability
Thermally accelerated drift thermal-mechanical monitoring	60	Monitoring drift and invert shape and integrity in a thermally accelerated drift.	Engineered Barrier System, Retrievability
3. DESIGN TESTING (OTHER THAN WASTE PACKAGES)			
Seal testing	200	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.	Engineered Barrier System, Upper Natural Barrier
4. MONITORING AND TESTING OF WASTE PACKAGES			
Waste package monitoring	83	Remote monitoring for evidence of external corrosion of the waste package.	Engineered Barrier System
Corrosion testing	222	Corrosion testing in the laboratory of waste package 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.	Engineered Barrier System
Corrosion testing of thermally accelerated drift samples	223	Corrosion testing in the laboratory of waste package and drip shield samples exposed to conditions in the thermally accelerated drifts. Includes corrosion model applicability and laboratory testing of general corrosion, phase transformations of Alloy 22; and localized corrosion.	Engineered Barrier System
Waste form testing	226	Waste form testing (including waste package coupled effects) in the laboratory under internal waste package conditions.	Engineered Barrier System

NOTE: U = uranium; Sr - strontium; O = oxygen; Cl = chlorine; H = hydrogen; C = carbon; Tc = technetium; I = iodine.

1.4.3 Retrievability Activities

Specific requirements for waste retrievability are described in 10 CFR 63.111(e)(1) as:

> The geologic repository operations area must be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program.

Activities in the performance confirmation program are not expected to adversely impact retrievability, while some activities are intended to provide information to confirm the adequacy of the design, assumptions, and analyses supporting the option to retrieve waste. In situ drift stability will be confirmed, primarily by monitoring rockfall in the underground facility using regular inspection of non-emplacement and periodic inspection of emplacement drifts (Drift Inspection). The mechanical condition of thermally accelerated emplacement drifts will be monitored to detect significant physical changes in the drifts (Thermal-Mechanical Monitoring). Mechanical and deformational response of the emplacement and main drift excavation will be monitored prior to emplacement (Construction Effects Monitoring). These activities support monitoring to ensure that the option to retrieve waste is preserved. Section 3.3.1.8 contains a discussion of the drift inspection activities and the relationship to the retrieval requirement.

1.4.4 Performance Confirmation Activities Timing and Links to Site Characterization

Performance confirmation was started during site characterization and many of the selected performance confirmation program activities are extensions of site characterization tests. The scope, methods, and detailed procedures for these tests were not identical to those planned for performance confirmation and they will be reviewed and modified as necessary to satisfy performance confirmation requirements.

Section 5 describes the process by which the plans for tests that were initiated during site characterization will be revised. Section 5.2.4 provides a discussion of the continuation of these tests. Section 6 shows the planned timing for these activities. Detailed discussions of the planned activities are provided in Section 3.

1.5 RELATIONSHIP OF PERFORMANCE CONFIRMATION TESTING TO OTHER TESTING AND MONITORING PROGRAMS

1.5.1 Project Testing and Monitoring Program

The overall Yucca Mountain testing and monitoring program is flexible and will evolve with time related to the stage of repository development (e.g., construction or operations), regulatory requirements, and the continuing refinement of the understanding of the repository system. In addition, as technology advances, needs change, or tests are completed and no longer add value; the programs will change to accommodate the new information.

There are many categories of testing and monitoring programs required to design, construct, operate, and close the repository. These include: performance confirmation testing and monitoring; design construction and operations testing; licensing specification testing; security, safeguards, and emergency testing; regulatory directed research and development testing; natural and engineered systems testing and evaluation; science and technology program; and health and safety effluents monitoring. The documented results of many of these programs will be required to satisfy the regulatory requirements for the repository. The criteria by which activities will be evaluated for inclusion into a given category of the testing and monitoring program, the functions each category addresses, and the current list of activities in each category will be developed at the appropriate times. Performance confirmation is just one of eight currently identified categories of the testing and monitoring program (discussed below), and is specifically identified as the set of monitoring and testing necessary to satisfy the requirements of 10 CFR Part 63, Subpart F. It should be recognized that like the repository design, test planning for many of the categories would be at a preliminary stage of development at the License Application for Construction Authorization. A high-level categorization of the future Yucca Mountain testing and monitoring programs (eight categories) is presented here. A letter (Mitchell J.T. 2004 [DIRS 170294]) describes the eight-category outline for the plan to provide definition and interfaces for the testing and monitoring program. The Project is currently developing a more comprehensive description of the testing and monitoring program that will be available as a Project document. This document will more thoroughly describe how future testing will be managed and evaluated and expand upon the criteria for evaluation listed below.

1. **Performance Confirmation Testing and Monitoring**–The purpose and objectives of this program, as stated in regulation 10 CFR 63.102(m) are that "a performance confirmation program will be conducted to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Key geotechnical and design parameters, including any interactions between natural and engineered systems and components, will be monitored throughout site characterization, construction, emplacement, and operation to identify any significant changes in the conditions assumed in the License Application that may affect compliance with the performance objectives specified at 10 CFR 63.113(b) and (c)." Although the primary focus of the performance confirmation program is on postclosure performance of the repository, the program also includes activities to address the preservation of the ability to retrieve waste.

2. **Design Construction and Operations Testing**–Testing that is used to verify conformance of an item to specified requirements, or to demonstrate satisfactory performance for service. Examples of these types of tests include:

   Prototype Evaluation Testing–Prototyping evaluations and testing of complex first-of-a-kind items (e.g., waste package, waste package closure, waste package emplacement gantry) to confirm fabrication methods, welding techniques and equipment, and effectiveness of nondestructive examination methods. Testing data are used to confirm or modify equipment design, fabrication and/or inspection.

   Design/Construction and Startup Testing–Testing of natural systems (geotechnical information) to confirm data used as input to the preclosure design. Testing of construction materials (e.g., concrete) to confirm materials properties used in the design. Testing conducted during construction, startup and preoperational periods on components, subsystems and systems to confirm their functional and operational performance. Testing data are used to confirm design analytical bases and operational readiness.

   Operations and Maintenance Testing–Planned operations and maintenance testing of equipment, operating systems and safety systems to confirm operating performance of systems, safety system availability, and to confirm the maintenance program is adequate. Testing data are used to confirm that systems perform as intended, and to meet NRC inspection needs.

3. **License Specifications Testing**–Testing and monitoring to comply with NRC licensing specifications issued as a part of the License Application for the facility to ensure analyzed safety bases are met. Testing data are used to allow for operations within the confines of the license and for evaluation and compliance reporting to the NRC for the preclosure period.

4. **Security, Safeguards, and Emergency Testing**–Testing to confirm functional performance of the security, safeguards, and emergency systems. Testing data are used to document systems adequacy and required NRC regulatory reporting for the preclosure period.

5. **Regulatory Directed Testing Programs**–NRC may require that additional testing be conducted as part of the license. These tests may include:

   NRC Required Research and Development Safety Testing–Research and development programs are established by NRC mandated conditions of the License Application to resolve safety questions. Testing data are used for reporting NRC resolution of conditions of the license when directed by NRC.

   NRC 10 CFR 63.74(a) Requested Testing–Performance of tests specified by NRC under 10 CFR 63.74(a). Testing data are used to respond to NRC specified tests.

6. **Natural and Engineered Systems Testing and Evaluation**–DOE may elect to conduct testing that relates to needs identified both internally and externally to refine models and reduce uncertainties. Examples include:

   DOE Elective Testing in Response to NRC Questions–DOE elective testing/monitoring resulting from NRC review of the License Application. Testing data may be used to respond to NRC Request for Additional Information. An example of such an activity is the aeromagnetic survey conducted and the associated planned drilling program to advance the understanding of the number and age of basaltic volcanic centers in the site vicinity.

   DOE Elective Testing–DOE elective testing and monitoring activities selected to evaluate current model uncertainties and/or conservatism. The testing data collected are used to consider modification of a TSPA input abstraction, process model or data use in order to strengthen technical arguments or evaluate margin. Testing will occur as DOE determines need for additional information.

7. **Health, Safety and Effluents Monitoring**–Testing and monitoring that relate to the needs identified by regulatory programs aimed at environmental and worker protection during preclosure, including:

   Environmental Safety and Health Compliance Monitoring–Environmental, safety and health testing and monitoring to confirm public and worker health and safety and to demonstrate compliance with permits. Testing data are used for monitoring and reporting to the permitting agencies (Occupational Safety and Health Administration and DOE for the preclosure period).

   Site Effluent Testing–Monitoring and testing to show compliance with effluent release requirements. Testing data are used for monitoring and reporting to the State of Nevada, U.S. Environmental Protection Agency, and NRC for the preclosure period.

8. **Science and Technology Program**–Research and development testing that relates to advances in science and technology intended to lead to development of new models, expectations, or theories of behavior for the natural system, waste form, or waste package materials, including:

   Natural Systems Science and Technology Testing for Long-Term Barrier Performance–Research and development tests to develop long-term Barrier performance enhancements. Testing data are used in the future in TSPA for modified performance predictions.

   Engineered Systems Science and Technology for Long-Term Engineered Systems Operations Performance–Research and development tests to develop long-term facility operational and/or TSPA performance improvements. Testing data are used for future facility and/or operational design modifications.

1.5.2 Project Integration of Performance Confirmation

Performance confirmation at a first-of-its-kind geologic repository that relies on two natural barriers and the Engineered Barrier System is neither intuitive nor simple. Reliance on rote methodologies will not be adequate, especially since the activities are focused on confirming information used to project postclosure performance thousands of years beyond the performance confirmation period. A Performance Confirmation Integration group is planned to review performance confirmation data and evaluate the overall status of the program. Also, the Performance Confirmation Integration group will be designed to ensure continuity and integration with other testing and monitoring programs, as described in Section 1.5.1, through participants that are cognizant of other project testing activities and through interface with investigators in other programs.

The group would evaluate whether the incremental results within performance confirmation are interrelated, technically adequate, properly documented, and properly evaluated. This evaluation will ensure that barrier and system performance is assessed in the context of all relevant performance confirmation information. Reporting to NRC is planned consistent with overall reporting requirements for performance confirmation.

Because observation durations can be short (e.g., geologic mapping only during active construction of the repository) compared to the expected period of performance of the barrier after permanent closure, this group would consider whether analyses considering very low probability events (such as major seismic or volcanic events) should be revisited based on a better understanding of subsurface conditions and reduction in uncertainty on probability of rare unexpected or unusual events.

The integration group would address issues common to performance confirmation. The selection of members would include those knowledgeable of other testing and monitoring programs noted in Section 1.5.1 such that shared use of data and data management systems could be achieved. Reporting from the group is planned and could support notifications to the NRC if deviations from the expected ranges occur.

Formalized periodic meetings would provide a structured forum where professionals and subject matter experts interact about performance confirmation results, and other program areas, as applicable. In this way, different experts with different job functions and areas of expertise can review performance confirmation data in addition to results from other related programs. These evaluations will help determine whether new information could potentially impact performance confirmation activities or other testing areas of responsibility, thereby possibly changing representations of the integrity of the geologic repository.

In addition, considerable advances in technology can be expected to occur over the next several decades. A successful performance confirmation program is flexible, and includes a process to reevaluate, reexamine, and modify performance confirmation activities as the state of understanding changes. New tests may be needed, or may become possible with new technology, and tests that are not providing useful information should be discontinued. Some parameters are difficult to measure but nonetheless may be important to evaluating information used in the licensing basis. An integration group and workshop approach facilitates developing and correlating new data, to the extent feasible, to build a body of evidence that will improve the performance knowledge base.

1.6 ORGANIZATION OF THE PERFORMANCE CONFIRMATION PLAN

Section 1 of this *Performance Confirmation Plan* explains the purpose, objectives, scope, and quality assurance provisions applicable to implementation of the performance confirmation program. It contains a subsection that outlines the risk-informed, performance-based process used to select the current list of 20 activities. The section provides a Table 1-1 that lists those activities and groups the activities into the four principal YMRP NUREG-1804 (NRC 2003 [DIRS 163274]) acceptance criteria categories. The section provides an overview of the three barriers important to waste isolation and some preliminary discussion (more detail in Section 3) at how the activities address each barrier. It also provides Figures 1-1 and 1-2 that illustrate natural features and engineered components of the barriers. In addition, the section provides the discussion of other Project testing and monitoring programs and the criteria for segregating testing programs into each. Within the discussion of the other testing and monitoring programs, the plans for a testing programs working group are described.

Section 2 provides high-level traceability to the 10 CFR Part 63 regulatory requirements and other for the *Performance Confirmation Plan*. Two crosswalk tables, (in Sections 2.2.1 and 2.2) are provided to demonstrate where the specific provisions are addressed. The table in Section 2.2.1 covers the 10 CFR Part 63 requirements and the table in Section 2.2 covers the YMRP NUREG-1804 (NRC 2003 [DIRS 163274]) Acceptance Criteria, relating activities and sections within the document where the criteria and requirements are addressed.

Section 3 describes the planned performance confirmation test activities for the performance confirmation program. The section begins with a discussion that describes the interrelationships of the three barriers to the performance confirmation activities supporting the barrier analysis. The section then lists each of the 20 activities, grouped according to the four acceptance criteria categories (NRC 2003 [DIRS 163274]). For each activity, the section provides a title, description, selection justification (both technical and regulatory), a description of the current understanding of each activity, and the anticipated methodology for fielding the test. The descriptions also provide, where available, the citations to the documents in which the baseline will be found. The activity descriptions also identify whether the activity includes in situ monitoring, laboratory, or field methods and states the reason why the activity is not expected to adversely affect the ability of the repository to meet performance objectives.

Section 4 discusses the approach to, and the preliminary development of, the performance confirmation program baseline data. The performance confirmation program baseline data will be updated, when required, to incorporate repository performance analysis and design as they evolve. Section 4 also addresses trend detection, analysis, internal and external (e.g., NRC) reporting, and action ranges.

Sections 5 and 6 describe the development of Performance Confirmation Test Plans and procedures, and the performance confirmation schedule, respectively. Experiment design and test planning for performance confirmation activities are included, specifically describing PC Test Plans. The use and roles of laboratory and field implementation procedures, documents, and reports are described, including the use of field work packages, technical procedures, scientific notebooks, work orders, and implementation records. A table is provided in Section 5 that identifies the 11 activities initiated or conducted during site characterization and a listing of their current test plan and field work package. Section 6 places these 11 activities, and the other 9 that have not yet begun, in timeline with other Project milestones and activities.

Section 7 provides a list of references used in the *Performance Confirmation Plan*.

Appendix A provides a glossary of terms.

Conventions–A number of conventions are used in this report relating to the use of performance confirmation and performance assessment to reduce confusion. The *Performance Confirmation Plan* describes the performance confirmation program that includes tests, experiments, and analyses to evaluate the accuracy and adequacy of the information used to demonstrate compliance with the postclosure performance objectives in 10 CFR Part 63, Subpart E. The PC Test Plans, the next level of plan below the *Performance Confirmation Plan,* provide details at the activity or test level. Performance assessment includes analyses of the behavior of a system or system component under a given set of conditions. TSPA-LA is the highest level of many assessments that are used to evaluate barrier capability.

1.7 QUALITY ASSURANCE

The performance confirmation program will be conducted in compliance with 10 CFR Part 63, Subpart F, including 10 CFR 63.142. The *Performance Confirmation Plan* was prepared in accordance with implementing procedure LP-3.11Q-BSC, *Technical Reports* ([DIRS 171737]) and is subject to the *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171386]).

INTENTIONALLY LEFT BLANK

2. REQUIREMENTS AND GUIDANCE

This section describes NRC's regulatory requirements and guidance applicable to the DOE performance confirmation program. The regulatory definition for performance confirmation is provided and specific requirements in 10 CFR Part 63 ([DIRS 156605]) are identified. A crosswalk between individual performance confirmation activities described in this plan and the 10 CFR Part 63 requirements is included. A similar crosswalk relating to the acceptance criteria from the YMRP NUREG-1804 (NRC 2003 [DIRS 163274]) is also provided.

2.1 REGULATORY SCOPE OF THE PERFORMANCE CONFIRMATION PROGRAM

The performance confirmation program developed for the Yucca Mountain repository is directed at evaluating the adequacy of the information used to demonstrate compliance with the performance objectives in 10 CFR Part 63. Regulatory requirements exclusively applicable to the performance confirmation program are specified in 10 CFR Part 63, Subpart F. A description of the performance confirmation program is required in the SAR as part of the License Application (10 CFR 63.21(c)(17)). Guidance for NRC staff review of the description of the program is provided in the YMRP NUREG-1804, (NRC 2003 [DIRS 163274]).

As defined at 10 CFR 63.2, performance confirmation is:

> The program of tests, experiments, and analyses that is conducted to evaluate the adequacy of the information used to demonstrate compliance with the performance objectives in subpart E.

10 CFR Part 63, Subpart E includes both preclosure and postclosure performance objectives and further defines the performance confirmation concept at 10 CFR 63.102(m):

> A performance confirmation program will be conducted to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Key geotechnical and design parameters, including any interactions between natural and engineered systems and components, will be monitored throughout site characterization, construction, emplacement, and operation to identify any significant changes in the conditions assumed in the license application that may affect compliance with the performance objectives specified at § 63.113(b) and (c).

The phrase "findings that permitted construction of the repository and subsequent emplacement of the wastes" refers to the safety determinations required of NRC at 10 CFR 63.31(a)(1) to authorize construction:

> (1) That there is reasonable assurance that the types and amounts of radioactive materials described in the application can be received and possessed in a geologic repository operations area of the design proposed without unreasonable risk to the health and safety of the public; and

(2) That there is reasonable expectation that the materials can be disposed of without unreasonable risk to the health and safety of the public.

These findings respectively relate to preclosure and postclosure aspects of repository operation and performance.

The Supplementary Information for 66 FR 55732 ([DIRS 156671]) explains that:

> Although the primary focus of the performance confirmation program is on postclosure performance, it is important that the general requirements also include consideration of operations aspects of repository performance, for example, the ability to retrieve waste as required by 63.111(e). [66 FR 55732, [DIRS 1566771] p. 55744]

Furthermore, the YMRP NUREG-1804 (NRC 2003, [DIRS 163274]) Section 2.4.1 provides elaboration:

> The broad reference to the performance objectives under subpart E in the performance confirmation definition reflects the need to consider retrievability when monitoring subsurface conditions, and that preserving the retrieval option is a preclosure performance requirement. The general requirements for the performance confirmation program do not require testing and monitoring to confirm preclosure performance in other contexts.

Thus, the scope of the performance confirmation program is directed at evaluating information supporting compliance arguments for the postclosure performance objectives for individual protection (10 CFR 63.113(b)) and groundwater protection (10 CFR 63.113(c)), and the preclosure performance objective for retrievability (10 CFR 63.111(e)).

Consistent with the regulatory approach for 10 CFR Part 63 the activities in the performance confirmation program should be risk-informed and performance-based. They need not go beyond what is practicable (10 CFR 63.131(a)) and necessary to meet the requirements of 10 CFR Part 63, Subpart F. Performance confirmation includes activities such as in situ monitoring and testing, laboratory and field-testing, surveillance and measurement, and monitoring of conditions. The performance confirmation program is focused on those activities necessary to identify and evaluate significant changes in the conditions assumed in the License Application that may affect compliance with the specified performance objectives for retrievability, individual protection, and groundwater protection. Monitoring subsurface conditions and testing to confirm geotechnical and design assumptions addresses compliance with the preclosure aspect of performance confirmation to ensure the preservation of the retrievability option.

The capabilities of barriers identified as important to waste isolation are key to demonstrating compliance with the postclosure performance objectives for individual and groundwater protection. Barrier functions prevent or substantially reduce the rate of movement of water or radionuclides from the repository to the accessible environment, or prevent the release or substantially reduce the release rate of radionuclides from the waste. Definition of the barriers important to waste isolation and of the processes and conditions that may significantly affect the capabilities of these barriers provides a risk-informed, performance-based basis for determining the scope of the postclosure aspects of the performance confirmation program.

The performance confirmation requirements in 10 CFR Part 63, Subpart F emphasize making physical observations or measurements in the underground environment available during construction and through waste emplacement operations. Several broad divisions of interest are apparent. One is the confirmation that actual subsurface conditions, including changes in those conditions attendant to construction and waste emplacement, are as expected. A second is the evaluation of barrier functionality, which is integral to the safety analyses. Another is the testing of the engineered system and components used in the design and not intended for installation until late in repository development.

In summary, the performance confirmation program must:

- Confirm that subsurface conditions, geotechnical and design parameters are as anticipated and that changes to these parameters are within limits assumed in the License Application

- Confirm that the waste retrieval option is preserved (see Section 1.6 and Section 3)

- Evaluate information used to assess whether natural and engineered barriers function as intended

- Evaluate effectiveness of design features intended to perform a postclosure function during repository operation and development

- Monitor waste package condition.

The performance confirmation program began during site characterization and will continue until permanent closure of the repository (10 CFR 63.131(b)). Relevant site characterization information is incorporated into the baseline for implementation of performance confirmation during repository construction and operation (Section 4). Section 1.1 listed the activities that began during site characterization and those that will begin at later stages in the repository development. A variety of testing and monitoring is anticipated as part of repository development and operation. As described in Section 1.5, the performance confirmation constitutes only one aspect of testing to be conducted in support of repository development.

An update of the performance assessment of the repository is required in the license amendment for permanent closure (10 CFR 63.51(a)(1)). The updated assessment must include any parameter measurements collected under the program required by 10 CFR Part 63, Subpart F and pertinent to compliance with the postclosure performance objectives in 10 CFR 63.113. As a result, one of the objectives of performance confirmation is to support the analytical bases for the evaluations of the individual and groundwater postclosure performance objectives that will be relied upon by the NRC in its decision to permit permanent closure of the repository.

Although the primary focus of the performance confirmation program is on postclosure performance of the repository, the program also includes activities to address the preservation of the ability to retrieve waste. Assurance that operational and administrative controls of processes like materials qualification, waste acceptance, waste package testing and handling is addressed outside the context of performance confirmation.

2.2 PERFORMANCE CONFIRMATION PLAN–10 CFR PART 63 REGULATORY REQUIREMENTS

This section identifies performance confirmation requirements and explains relationships between the requirements, and the *Performance Confirmation Plan* activities to demonstrate regulatory compliance for the performance confirmation program.

2.2.1 Performance Confirmation Requirements in 10 CFR Part 63

Performance confirmation is specifically addressed in 10 CFR Part 63, Subpart F. Other regulatory provisions related to performance confirmation are contained in 10 CFR Part 63, Subparts A, B, D, E, and G. Subpart A (10 CFR 63.2) defines the term performance confirmation to mean "the program of tests, experiments, and analyses that is conducted to evaluate the adequacy of the information used to demonstrate compliance with the performance objectives in Subpart E of this part."

Subpart B (10 CFR 63.21(c)(17)) requires that a description of the performance confirmation program be included in the License Application SAR. Subpart B (10 CFR 63.51(a)(1)) also requires that parameter measurements obtained during construction and operations under the program required by Subpart F and pertinent to compliance with 10 CFR 63.113 (postclosure performance objectives) be included in the application for a license amendment for permanent closure.

Subpart D (10 CFR 63.74) identifies the performance confirmation program as one particular category of tests the Commission considers necessary to administer its regulation.

Subpart E includes several references to performance confirmation. Two occurrences elaborate on the concept. The duration of the performance confirmation program is described in the context of the stages of the licensing process as beginning during site characterization and extending until permanent closure (10 CFR 63.102(c)). Refinement of the definition of performance confirmation at 10 CFR 63.2 is provided in Subpart E (10 CFR 63.102(m)).

Two additional references to performance confirmation in Subpart E are provided at 10 CFR 63.111. These references do not provide direction relative to performance confirmation. One constrains design activities to assure that a performance confirmation program that meets the requirements of Subpart F can be implemented (10 CFR 63.111(d)). The other conditions the requirement to maintain the option of waste retrieval until completion of the performance confirmation program and NRC review of the information obtained from that program (10 CFR 63.111(e)).

Subpart F stipulates the specific requirements for the performance confirmation program. These provisions detail expectations for the performance confirmation program using both technical requirements and administrative directives that generally apply to the implementation of the performance confirmation program. In evaluating Subpart F provisions it is important to keep in mind that the principal interest is directed at changes that might impact compliance with the postclosure performance objectives for individual and groundwater protection. Collection of information to evaluate the bases for repository design, including those relied upon to preserve the retrieval option, is also required.

While the regulation may specify "parameters" in some places, this plan uses a term "activity" which is the combination of test parameters and test methods (the combination is referred to as a test or monitoring activity). It should be understood that test parameters are at a lower level than activities and will be detailed and described in the PC Test Plans. Section 3.2 provides a list of the parameters and purpose for each activity.

Table 2-1 relates 10 CFR Part 63 requirements to individual activities in this plan. In the individual activity descriptions in Section 3, a more detailed, consolidated listing of which requirements each activity addresses is provided.

The general requirements of Subpart F (10 CFR 63.131) set the emphasis for subsequent specific direction. The performance confirmation program is to be designed such that observations and measurements in the repository subsurface can evaluate conditions described in the License Application, and identify significant differences from expected conditions (10 CFR 63.131(a)(1)). Similarly, the program needs to include tests to identify changes that may result from excavating the drifts or emplacement of waste packages and the resulting thermal effects. Paragraph 10 CFR 63.131(a)(2) directs performance confirmation to evaluate the functionality of barriers important to waste isolation. Paragraphs 10 CFR 63.131(b) through 10 CFR 63.131(d)(3) provides administrative direction that applies to overall implementation of the performance confirmation program.

10 CFR 63.132 elaborates on the general requirement specified at 10 CFR 63.131(a)(1). It emphasizes mapping and measurement of geotechnical conditions and the design parameters necessary to evaluate the need for construction method or design changes either because of subsurface conditions encountered (10 CFR 63.132(a)), or impacts on performance (10 CFR 63.132(d) and (e)). Subparagraph (b) and (c) of this section require specific identification of what is to be measured and an evaluation of observations and results obtained against design assumptions used in the SAR.

10 CFR 63.133 requires testing of engineered systems and components included in the design.

10 CFR 63.134 requires monitoring and testing of waste packages and elaborates on the general requirement at 10 CFR 63.131(a)(2), the waste package being identified as a barrier important to waste isolation.

Subpart G (10 CFR 63.142(a)) includes performance confirmation activities within the activities related to barrier design and characterization important to waste isolation, and thereby subject to the quality assurance program.

Table 2-1. Provisions from Subpart F Paragraphs 10 CFR 63.131 through 10 CFR 63.134

10 CFR Part 63 Section Performance Confirmation Activities Subpart F Performance Confirmation Program	
§ 63.131 General requirements	**Regulatory Compliance Activities**
(a) The performance confirmation program must provide data that indicate, where practicable, whether:	
(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 (3.3.1.2) Drift Inspection (3.3.1.8) Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Thermally Accelerated Drift In-Drift Environment Monitoring (3.3.1.11) Subsurface Mapping (3.3.2.1) Seismicity Monitoring (3.3.2.2.) Construction Effects Monitoring (3.3.2.3) Thermally Accelerated Drift Thermal-Mechanical Monitoring (3.3.2.4) Surface Water and Rock Testing (3.3.1.3)
(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 (3.3.1.1) Seepage Monitoring (3.3.1.2) Subsurface Water and Rock Testing (3.3.1.3) Unsaturated Zone Testing (3.3.1.4) Saturated Zone Monitoring (3.3.1.5) Saturated Zone Fault Hydrology Testing (3.3.1.6) Saturated Zone Alluvium Testing (3.3.1.7) Drift Inspection (3.3.1.8) Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Dust Buildup Monitoring (3.3.1.10) Thermally Accelerated Drift In-Drift Environment (3.3.1.11) Subsurface Mapping (3.3.2.1) Seismicity Monitoring (3.3.2.2) Construction Effects Monitoring (3.3.2.3) Thermally Accelerated Drift Thermal-Mechanical Monitoring (3.3.2.4) Seal Testing (3.3.3.1) Waste Package Monitoring (3.3.4.1) Corrosion Testing (3.3.4.2) Corrosion Testing of Thermally Accelerated Drift Samples (3.3.4.3) Waste Form Testing (3.3.4.4.)
(b) The program must have been started during site characterization, and it will continue until permanent closure.	Performance Confirmation Program Implementation (6.0 Schedule)
(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.	Performance Confirmation Program Implementation (3.0 Description of Performance Confirmation Activities)
(d) The program must be implemented so that:	
(1) It does not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives.	Performance Confirmation Program Implementation (1.2 Purpose and Objectives of the Performance Confirmation Plan and Program)
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.	Performance Confirmation Program Implementation (4.0 Data Management, Analyses, and Reporting)
(3) It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository.	Performance Confirmation Program Implementation (4.0 Data Management, Analyses, and Reporting)

Table 2-1. Provisions from Subpart F Paragraphs 10 CFR 63.131 through 10 CFR 63.134 (Continued)

10 CFR Part 63 Section Performance Confirmation Activities Subpart F Performance Confirmation Program	
§ 63.132 Confirmation of geotechnical and design parameters	**Regulatory Compliance Activities**
(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 (3.3.1.2) Drift Inspection (3.3.1.8) Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Thermally Accelerated Drift In-Drift Environment (3.3.1.11) Subsurface Mapping (3.3.2.1) Seismicity Monitoring (3.3.2.2) Construction Effects Monitoring (3.3.2.3) Thermally Accelerated Drift Thermal-Mechanical Monitoring (3.3.2.4)
(b) Subsurface conditions must be monitored and evaluated against design assumptions.	Seepage Monitoring (3.3.1.2) Drift Inspection (3.3.1.8) Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Thermally Accelerated Drift In-Drift Environment (3.3.1.11) Subsurface Mapping (3.3.2.1) Construction Effects Monitoring (3.3.2.3) Thermally Accelerated Drift Thermal-Mechanical Monitoring (3.3.2.4)
(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.	Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Subsurface Mapping (3.3.2.1) Construction Effects Monitoring (3.3.2.3) Thermally Accelerated Drift Thermal-Mechanical Monitoring)(3.3.2.4)
(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.	Performance Confirmation Program Implementation (4.0 Data Management, Analyses, and Reporting)
(e) In situ monitoring of the thermomechanical 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 (3.3.1.8) Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Thermally Accelerated Drift Thermal-Mechanical Monitoring (3.3.2.4)
§ 63.133 Design testing	**Regulatory Compliance Activities**
(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 (3.3.1.2) Thermally Accelerated Drift Near-Field Monitoring (3.3.1.9) Thermally Accelerated Drift In-Drift Environment (3.3.1.11) Construction Effects Monitoring (3.3.2.3) Thermally Accelerated Drift Thermal-Mechanical Monitoring (3.3.2.4) Seal Testing (3.3.3.1)
(b) The testing must be initiated as early as practicable.	Performance Confirmation Program Implementation (6.0 Schedule)
(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 Testing (3.3.3.1)
(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 Testing (3.3.3.1)

Table 2-1. Provisions from Subpart F Paragraphs 10 CFR 63.131 through 10 CFR 63.134 (Continued)

10 CFR Part 63 Section Performance Confirmation Activities Subpart F Performance Confirmation Program	
§ 63.134 Monitoring and testing waste packages	**Regulatory Compliance Activities**
(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.	Drift Inspection (3.3.1.8) Dust Buildup Monitoring (3.3.1.10) Waste Package Monitoring (3.3.4.1)
(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.	Performance Confirmation Program Implementation (3.0 Description of Performance Confirmation Activities)
(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.	Dust Buildup Monitoring (3.3.1.10) Corrosion Testing (3.3.4.2) Corrosion Testing of Thermally Accelerated Drift Samples (3.3.4.3) Waste Form Testing (3.3.4.4)
(d) The waste package monitoring program must continue as long as practical up to the time of permanent closure.	Performance Confirmation Program Implementation (6.0 Schedule)

Several sections of 10 CFR Part 63 that are not specifically identified as applicable to performance confirmation may be important considerations in execution of the program. Certain provisions related to records and reports (10 CFR 63.71) and construction records (10 CFR 63.72) clearly apply to performance confirmation. Also, depending on the circumstances, provisions related to changes, tests, and experiments (10 CFR 63.44) and reports of deficiencies (10 CFR 63.73) are applicable to performance confirmation.

Technical provisions of 10 CFR Part 63, Subpart F are addressed by applying a process designed to satisfy the technical approach implicit in the regulation. The activities described in Section 3 incorporate such an approach using the following basic steps:

- Identify physical characteristic(s) or parameter(s) important to the evaluation
- Establish the value or range of values for characteristics or parameters that will be measured
- Identify the type and expected magnitude of changes that may occur in the baseline
- Monitor or test identified parameters to evaluate assumed values for changes
- Analyze the outcomes of the monitoring or test activity by comparing results to the established baseline or design assumptions

- Decide if the outcome is such that changes in construction, design, or performance assessment approaches may be necessary
- Report the impact to NRC if an appropriate threshold is met.

Compliance with the provisions of 10 CFR Part 63, Subpart F is accomplished (refer to Table 2-1) by evaluating:

- The subsurface conditions encountered during construction (10 CFR 63.131(a)(1)). This also includes the surveillance and mapping provisions of 10 CFR 63.132(a)
- Changes in the subsurface conditions resulting from construction and waste emplacement (10 CFR 63.131(a)(1)) and thermal-mechanical response (10 CFR 63.132)
- Natural systems and components assumed to operate as barriers after permanent closure emplacement (10 CFR 63.131(a)(2))
- Engineered systems and components assumed to operate as barriers after permanent closure emplacement (10 CFR 63.131(a)(2)), including waste package monitoring and testing (10 CFR 63.134)
- Testing engineered systems and components used in the design (10 CFR 63.133).

The administrative elements of 10 CFR Part 63, Subpart F are addressed (refer to Table 2-1) by their incorporation into the implementation architecture of the performance confirmation program plan in Section 5. Compliance with the following provisions is accomplished directly through program planning and execution:

- Initiating performance confirmation during site characterization and maintaining the program until repository closure (10 CFR 63.131(b))
- Including appropriate in situ monitoring, laboratory and field-testing, and in situ experiments in the program (10 CFR 63.131(c))
- Implementing the program so as to not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives (10 CFR 63.131(d)(1))
- Conducting in situ monitoring of thermal-mechanical response of the underground facility until permanent closure (10 CFR 63.132(e))
- Initiating design testing as early as practicable during construction (10 CFR 63.133(b))
- Conducting design testing during the early or developmental stages of construction for components such as boreholes, shafts, and ramps (10 CFR 63.133(a))

- Monitoring representative waste packages at the geologic repository operations area (10 CFR 63.134(a)), in an environment representative of waste emplacement (10 CFR 63.134(b)), and continuing that monitoring as long as practical up to permanent closure (10 CFR 63.134(d))

- Conducting laboratory experiments that, to the extent practical, duplicate the environment experienced by the waste packages in the underground facility (10 CFR 63.134(c)).

The performance confirmation activities designed to comply with the requirements of 10 CFR Part 63, Subpart F are described in Section 3. Table 2-1 correlates the activities with specific provision in 10 CFR Part 63, Subpart F.

Implementation of the test and monitoring program described in Section 3, in conjunction with the approaches outlined in Sections 4 and 5, satisfies the requirements for performance confirmation in 10 CFR Part 63 because:

- It is designed to evaluate the adequacy of assumptions, data, and analyses that lead to the findings that permit construction of the repository and subsequent emplacement of wastes.

- It addresses each of the technical provisions specified in 10 CFR Part 63, Subpart F.

- Each of the administrative provisions in 10 CFR Part 63, Subpart F is incorporated in its implementation.

2.2.2 Evaluation of Performance Confirmation Guidance in the Yucca Mountain Review Plan, Final Report

Staff guidance for NRC review of information related to performance confirmation in a License Application submitted pursuant to 10 CFR Part 63 is presented in Section 2.4 of YMRP NUREG-1804 (NRC 2003 [DIRS 163274]). The structure of YMRP NUREG-1804 (NRC 2003 [DIRS 163274]) Section 2.4 and the acceptance criteria in Section 2.4.3 parallel the structure of 10 CFR Part 63, Subpart F.

The acceptance criteria from Section 2.4.3 of the YMRP NUREG-1804 (NRC 2003 [DIRS 163274]) are listed in Table 2-2. The section of this plan that addresses each of the technical and administrative provisions of Section 2.4.3 of YMRP NUREG-1804 (NRC 2003 [DIRS 163274]) is also identified in Table 2-2.

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections

YMRP Acceptance Criterion	Performance Confirmation Plan Section
Acceptance Criterion 1 The Performance Confirmation Program Meets the General Requirements Established for Such a Program.	
1 (1) The objectives of the performance confirmation program are consistent with the general requirements in that the program will provide data to indicate whether:	1.2 Purpose and Objectives of the Performance Confirmation Plan and Program
1 (1)(i) 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	3.3 Performance Confirmation Activities 3.3.1.2 Seepage Monitoring 3.3.1.8 Drift Inspection 3.3.1.9 Thermally Accelerated Drift Near-Field Monitoring 3.3.1.11 Thermally Accelerated Drift In-Drift Environment Monitoring 3.3.2.1 Subsurface Mapping 3.3.2.2 Seismicity Monitoring 3.3.2.3 Construction Effects Monitoring 3.3.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring
1 (1)(ii) natural and engineered systems and components that are designed or assumed to operate as barriers after permanent closure are functioning as intended and expected.	3.3 Performance Confirmation Activities 3.3.1.1 Precipitation Monitoring 3.3.1.2 Seepage Monitoring 3.3.1.3 Subsurface Water and Rock Testing 3.3.1.4 Unsaturated Zone Testing 3.3.1.5 Saturated Zone Monitoring 3.3.1.6 Saturated Zone Fault Hydrology Testing 3.3.1.7 Saturated Zone Alluvium Hydrology 3.3.1.8 Drift Inspection 3.3.1.9 Thermally Accelerated Drift Near-Field Monitoring 3.3.1.10 Dust Buildup Monitoring 3.3.1.11 Thermally Accelerated Drift In-Drift Environment Monitoring 3.3.2.1 Subsurface Mapping 3.3.2.2 Seismicity Monitoring 3.3.2.3 Construction Effects Monitoring 3.3.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring 3.3.3.1 Seal Testing 3.3.4.1 Waste Package Monitoring 3.3.4.2 Corrosion Testing 3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples 3.3.4.4 Waste Form Testing
1 (1) The performance confirmation plan provides sufficient technical information and plans for in situ monitoring, laboratory and field-testing, and in situ experiments to carry out the objectives in that:	

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
1 (1)(a) It identifies the natural and engineered systems and components that are designed or assumed to operate as barriers after permanent closure, including their specific functions, the U.S. Department of Energy selected to monitor and test, to ensure they are functioning as intended and expected;	3.2 Relationship of the Barriers and Activities
1 (1)(b) It includes the method used to select the natural and engineered systems and components, which are designed or assumed to operate as barriers after permanent closure, the U.S. Department of Energy will monitor and test, to ensure they are functioning as intended and expected;	1.4.1 Activity Selection Approach 3.2 Relationship of the Barriers and Activities
1 (1)(c) It identifies specific geotechnical and design parameters, pertaining to natural systems and components that are assumed to operate as barriers after permanent closure including natural processes and any interactions between natural and engineered systems and components, the U.S. Department of Energy selected to be measured or observed;	1.4.1 Activity Selection Approach 3.2 Relationship of the Barriers and Activities
1 (1)(d) It includes the method used to select the geotechnical and design parameters including any interactions between natural and engineered systems and components, the U.S. Department of Energy will measure or observe;	1.4.1 Activity Selection Approach
1 (1)(e) It includes specific in situ monitoring, laboratory and field-testing, and in situ experiments to acquire needed data;	3.3 Performance Confirmation Activities
1 (1)(f) It specifies which in situ monitoring, laboratory and field-testing, or in situ experimental methods the U.S. Department of Energy will apply to the selected: (i) geotechnical and design parameters, including natural processes, pertaining to natural systems and components that are assumed to operate as barriers after permanent closure; (ii) engineered systems and components that are designed or assumed to operate as barriers after permanent closure; and (iii) interactions between natural and engineered systems and components;	3.3 Performance Confirmation Activities
1 (1)(g) It includes the expected changes (i.e., design bases and assumptions) from baseline for the selected geotechnical and design parameters, including natural processes, pertaining to natural systems and components that are assumed to operate as barriers after permanent closure that will result from construction and waste emplacement operations; and	3.3 Performance Confirmation Activities 4.0 Data Management, Analysis, and Reporting
1 (1)(h) It includes the intended and expected design bases for the selected natural and engineered systems and components, which are designed or assumed to operate as barriers after permanent closure.	1.4.1 Activity Selection Approach 3.3 Performance Confirmation Activities 4.0 Data Management, Analysis, and Reporting 5.0 Test Planning and Implementation

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
1 (2) The schedule for the performance confirmation program is consistent with the general requirements. The program started during site characterization and will continue until permanent closure.	6.0 Schedule
1 (3) The U.S. Department of Energy will implement the performance confirmation program in a manner consistent with the general requirements in that:	
1 (3)(a) Procedures require the U.S. Department of Energy to consider adverse effects on the ability of the natural and engineered elements of the geologic repository to meet the performance objectives before initiating any in situ monitoring, tests, or experiments to acquire data;	5.0 Test Planning and Implementation
1 (3)(b) It provides baseline information and analysis of that information on those parameters and natural processes pertaining to pertaining to natural systems and components that are assumed to operate as barriers after permanent closure that may be changed by site characterization, construction, and operations;	3.3 Performance Confirmation Activities 4.0 Data Management, Analysis, and Reporting 5.0 Test Planning and Implementation
1 (3)(c) It commits to monitoring and analyzing changes from the baseline condition for those parameters and natural processes that could affect health and safety. Exceptions from this commitment for any particular parameter are identified and technically justified (refer to Acceptance Criterion 2 of this section);	4.0 Data Management, Analysis, and Reporting
1 (3)(d) It commits to monitoring engineered systems and components that are designed or assumed to operate as barriers after permanent closure to indicate whether they are functioning as intended and expected. Exceptions from this commitment for any particular system or component are identified and technically justified (refer to Acceptance Criterion 2 of this section); and	1.2 Purpose and Objectives of the Performance Confirmation Plan and Program 3.3 Performance Confirmation Activities
1 (3)(e) It provides terms for periodic assessment and update of the performance confirmation plan.	1.2 Purpose and Objectives of the Performance Confirmation Plan and Program 4.3 Trend Detection, Analysis, Reporting and Action Ranges
1 (4) The performance confirmation plan includes or cites procedures to meet the requirements for records and reports, specified at 10 CFR 63.71	5.0 Test Planning and Implementation
Acceptance Criterion 2 The Performance Confirmation Program to Confirm Geotechnical and Design Parameters Meets the Requirements Established for Such a Program.	
2 (1) The performance confirmation plan establishes a program for measuring, testing, and geologic mapping to confirm geotechnical and design parameters, including natural processes, pertaining to natural systems and components that are assumed to operate as barriers after permanent closure.	3.0 Description of Performance Confirmation Activities 3.3.2.1 Subsurface Mapping 3.3.2.2 Seismicity Monitoring 3.3.2.3 Construction Effects Monitoring 3.3.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
2 (1) The U.S. Department of Energy will implement the program during repository construction and operation. The program is consistent with the requirements in that:	6.0 Schedule
2 (1)(a) Geotechnical and design parameters the U.S. Department of Energy will monitor and analyze are selected using a performance-based method that focuses on those parameters that could affect health and safety.	1.4.1 Activity Selection Approach 3.3 Performance Confirmation Activities
2 (1)(a) The U.S. Department of Energy also considered the need to preserve the retrieval option;	1.0 Introduction 3.3.1.8 Drift Inspection
2 (1)(b) Results of performance assessments confirm the list of selected geotechnical and design parameters is reasonable and complete. The U.S. Department of Energy has justified excluding any geotechnical and design parameter that is important to waste isolation. Acceptable justification factors include the certainty provided by existing baseline information and the low likelihood of changes in that parameter as a result of construction, waste emplacement operations, or interactions between natural and engineered systems;	5.0 Test Planning and Implementation
2 (1)(c) The baseline of selected geotechnical and design parameters was determined using analytical or statistical methods appropriate for the particular parameter;	1.2 Purpose and Objectives of the Performance Confirmation Plan and Program 4.0 Data Management, Analysis, and Reporting
2 (1)(d) The baseline of selected geotechnical and design parameters considered all data available at the time of the submittal;	1.4.1 Activity Selection Approach
2 (1)(e) The effects of construction, waste emplacement operations, and interactions between natural and engineered systems are considered in the original design bases and assumptions for the geotechnical and design parameters; and	1.4.1 Activity Selection Approach 5.0 Test Planning and Implementation
2 (1)(f) Monitoring, testing, and experimental methods are suitable for the nature of individual parameters in terms of time, space, resolution, and technique. Instrumentation reliability and replacement requirements are considered;	5.0 Test Planning and Implementation
2 (2) The program includes adequate plans to monitor, in situ, the thermomechanical response of the underground facility until permanent closure. The program is consistent with the requirements in that:	3.0 Description of Performance Confirmation Activities 3.3.1.8 Drift Inspection 3.3.1.9 Thermally Accelerated Drift Near-Field Monitoring 3.3.2.3 Construction Effects Monitoring 3.3.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring
2 (2)(a) In situ thermomechanical response parameters that the U.S. Department of Energy will monitor and analyze are selected using a performance-based method that focuses on those parameters that could affect health and safety. The U.S. Department of Energy also considered the need to preserve the retrieval option;	1.4.1 Activity Selection Approach

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
2 (2)(b) Results of performance assessments confirm that the list of selected in situ thermomechanical response parameters is reasonable and complete. The U.S. Department of Energy has justified excluding any in situ thermomechanical response parameter that is important to waste isolation. Acceptable justification factors include the certainty provided by existing baseline information and the low likelihood of changes in that parameter as a result of construction, waste emplacement operations, or interactions between natural and engineered systems;	5.0 Test Planning and Implementation
2 (2)(c) The baseline of selected in situ thermomechanical response parameters was determined using analytical or statistical methods appropriate for the particular parameter;	4.0 Data Management, Analysis, and Reporting
2 (2)(d) The baseline of selected in situ thermomechanical response parameters considered all data available at the time of the submittal;	1.4.1 Activity Selection Approach
2 (2)(e) The effects of construction, waste emplacement operations, and interactions between natural and engineered systems are considered in the original design bases and assumptions for the in situ thermomechanical response parameters; and	1.4.1 Activity Selection Approach 5.0 Test Planning and Implementation
2 (2)(f) Monitoring, testing, and experimental methods are suitable for the nature of individual parameters in terms of time, space, resolution, and technique. Instrumentation reliability and replacement requirements are considered.	5.0 Test Planning and Implementation
2 (3) The performance confirmation plan sets up a surveillance program to evaluate subsurface conditions against design assumptions. The program is consistent with the requirements in that:	3.0 Description of Performance Confirmation Activities 3.3.2.1 Subsurface Mapping 3.3.2.2 Seismicity Monitoring 3.3.2.3 Construction Effects Monitoring 3.3.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring
2 (3)(a) It includes provisions for comparing measurements and observations with original design bases and assumptions. Comparisons are done routinely and in a timely manner to ensure that if any significant differences exist between the measurements and observations and the original design bases and assumptions, their significance to health and safety, and the need for design changes can be determined quickly and efficiently;	4.3 Trend Detection, Analysis, Reporting, and Action Ranges

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
2 (3)(b) It includes provisions for determining the need for modifications to the design or construction methods if significant differences exist between measurements and observations and original design bases and assumptions. Acceptable variations in the design bases and assumptions the design would accommodate without an adverse impact on health and safety have been provided. If construction methods or design needs to be modified to address changed conditions, the U.S. Department of Energy design control process used in the design phase may be used; and	4.3 Trend Detection, Analysis, Reporting, and Action Ranges
2 (3)(c) It includes provisions for reporting significant differences between measurements and observations and the original design bases and assumptions, their significance to health and safety and recommended changes to the Commission. These provisions meet the requirements for reports of deficiencies specified at 10 CFR 63.73.	4.3 Trend Detection, Analysis, Reporting, and Action Ranges
Acceptance criterion 3 The performance confirmation program for design testing meets the requirements established for such a program.	
3 (1) The performance confirmation plan establishes a program for design testing. The program is consistent with the requirements in that:	3.0 Description of Performance Confirmation Activities
3 (1)(a) Engineered systems and components the U.S. Department of Energy will test are selected using a performance-based method that focuses on those systems and components important to waste isolation;	1.4.1 Activity Selection Approach
3 (1)(b) Results of performance assessments confirm that the list of selected engineered systems and components is reasonable and complete. The U.S. Department of Energy has justified excluding any engineered system or component that is important to waste isolation from this program. An acceptable justification factor is the certainty that the system or component can perform its intended function;	5.0 Test Planning and Implementation
3 (1)(c) Testing methods are suitable for the particular engineered system or component being tested in terms of time, space, resolution, and technique. Testing methods are selected, in part, by considering the data needed to design the engineered systems and components. Test locations are selected considering compatibility with the environment in which the components or systems are to function. Instrumentation reliability and replacement requirements have been considered; and	5.0 Test Planning and Implementation
3 (1)(d) The effects of waste emplacement operations and interactions between natural and engineered systems are considered in estimates of the intended and expected design bases.	1.4.1 Activity Selection Approach 5.0 Test Planning and Implementation

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
3 (2) Thermal interaction effects of waste packages, rock, unsaturated zone and saturated zone water, and other engineered systems and components used in the design are included in the design testing program. The program is consistent with the requirements in that:	3.0 Description of Performance Confirmation Activities 3.3.1.8 Drift Inspection 3.3.1.9 Thermally Accelerated Drift Near-Field Monitoring 3.3.1.10 Dust Buildup Monitoring 3.3.1.11 Thermally Accelerated Drift In-Drift Environment Monitoring
3 (2)(a) Thermal interaction effects of waste packages, rock, unsaturated zone and saturated zone water, and other engineered systems and components the U.S. Department of Energy will test are selected using a performance-based method that focuses on those systems and components important to health and safety;	1.4.1 Activity Selection Approach
3 (2)(b) Results of performance assessments confirm that the list of selected thermal interaction effects of waste packages, rock, unsaturated zone and saturated zone water, and other engineered systems and components is reasonable and complete. The U.S. Department of Energy has justified excluding any thermal interaction effects of waste packages, rock, unsaturated zone and saturated zone water, and other engineered systems and components that are important to waste isolation from this program. An acceptable justification factor is the certainty that the system or component can perform its intended function;	5.0 Test Planning and Implementation
3 (2)(c) Testing methods are suitable for the particular thermal interaction effects of waste packages, rock, unsaturated zone and saturated zone water, and other engineered systems and components being tested in terms of time, space, resolution, and technique. Testing methods are selected, in part, by considering the data needed to design the thermal interaction effects of waste packages, rock, unsaturated zone and saturated zone water, and other engineered systems and components. Test locations are selected considering compatibility with the environment in which the components or systems are to function. Instrumentation reliability and replacement requirements have been considered; and	3.0 Description of Performance Confirmation Activities 5.0 Test Planning and Implementation
3 (2)(d) The effects of waste emplacement operations and interactions between natural and engineered systems are considered in estimates of the intended and anticipated performance limits (that is, design assumptions).	1.4.1 Activity Selection Approach 5.0 Test Planning and Implementation
3 (3) The design testing program requires that the effectiveness of backfill placement and compaction procedures against design requirements be demonstrated in an in situ test if backfill is included in the design. The importance of the contribution of the backfill to the long-term health and safety is considered in specifying testing requirements such as backfill material, gradation, and placement density, which are an indication of the water tightness or permeability of the backfill. Specifically:	3.3.3.1 Seal Testing

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
3 (3)(a) Backfill placement and compaction procedures the U.S. Department of Energy will test are selected using a performance-based method that focuses on those systems and components important to waste isolation;	3.3.3.1 Seal Testing
3 (3)(b) Results of performance assessments confirm that the list of selected backfill placement and compaction procedures is reasonable and complete. The U.S. Department of Energy has justified excluding any backfill placement and compaction procedures that are important to waste isolation from this program. An acceptable justification factor is the experience base in implementing placement and compaction procedures and the certainty of achieving the design bases for placement and compaction;	5.0 Test Planning and Implementation
3 (3)(c) Testing methods are suitable for the particular backfill placement and compaction procedures being tested in terms of time, space, resolution and technique. Testing methods are selected, in part, by considering the data needed to design the backfill placement and compaction procedures. Test locations are selected considering compatibility with the environment in which the components or systems are to function. Instrumentation reliability and replacement requirements have been considered; and	5.0 Test Planning and Implementation
3 (3)(d) The effects of waste emplacement operations and backfill placement and compaction procedure interactions between natural and engineered systems are considered in estimates of the intended and anticipated design bases.	5.0 Test Planning and Implementation
3 (4) The design testing program requires that the effectiveness of borehole, shaft, and ramp seals be demonstrated in a test before full-scale sealing. The importance of seals to the long-term performance of the repository is considered in planning the seal test program. Specifically:	3.0 Description of Performance Confirmation Activities 3.3.3.1 Seal Testing
3 (4)(a) The program of tests to evaluate the effectiveness of borehole, shaft, and ramp seals before full-scale sealing was selected, using a performance-based method that focuses on those systems and components important to waste isolation;	1.4.1 Activity Selection Approach
3 (4)(b) Results of performance assessments confirm that the program of tests to evaluate the effectiveness of borehole, shaft, and ramps seals, before full-scale sealing, is reasonable and complete. The U.S. Department of Energy has justified excluding any tests to evaluate the effectiveness of borehole, shaft, and ramp seals, before full-scale sealing, that are important to waste isolation, from this program. An acceptable justification factor is the certainty that the seals can perform their intended function considering the available experience base related to seals and the likelihood of achieving the design bases for seals;	5.0 Test Planning and Implementation

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
3 (4)(c) Testing methods are suitable for the particular program of tests to evaluate the effectiveness of borehole, shaft, and ramps seals before full-scale sealing, in terms of time, space, resolution and technique. Testing methods are selected, in part, by considering the data needed to design the program of tests to evaluate the effectiveness of borehole, shaft, and ramp seals before full-scale sealing. Test locations are selected considering compatibility with the environment in which the components or systems are to function. Instrumentation reliability and replacement requirements have been considered; and	5.0 Test Planning and Implementation
3 (4)(d) The effects of waste emplacement operations, and the program of tests to evaluate the effectiveness of borehole, shaft, and ramp seals, before full-scale sealing, on interactions between natural and engineered systems, are considered in estimates of the intended and anticipated design bases.	1.4.1 Activity Selection Approach 5.0 Test Planning and Implementation
Acceptance criterion 4 The performance confirmation program for monitoring and testing waste packages meets the requirements established for such a program.	
4 (1) The performance confirmation plan establishes a program for monitoring and testing the condition of waste packages at the geologic repository operations area. Further, the program is adequate because:	3.0 Description of Performance Confirmation Activities 3.3.1.8 Drift Inspection 3.3.4.1 Waste Package Monitoring 3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples
4 (1)(a) The waste packages the U.S. Department of Energy will monitor and test are representative of those to be emplaced in terms of materials, design, structure, fabrication, and inspection methods;	3.0 Description of Performance Confirmation Activities 3.3.1.8 Drift Inspection 3.3.4.1 Waste Package Monitoring 3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples
4 (1)(b) The environment of the waste packages the U.S. Department of Energy will monitor and test is representative of the emplacement environment, and is consistent with safe operations;	3.0 Description of Performance Confirmation Activities 3.3.1.8 Drift Inspection 3.3.4.1 Waste Package Monitoring 3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples
4 (1)(c) The environmental conditions the U.S. Department of Energy will monitor and evaluate include, but are not limited to, those describing water chemistry;	3.0 Description of Performance Confirmation Activities 3.3.1.2 Seepage Monitoring 3.3.1.8 Drift Inspection 3.3.1.9 Thermally Accelerated Drift Near-Field Monitoring 3.3.1.10 Dust Buildup Monitoring 3.3.1.11 Thermally Accelerated Drift In-Drift Environment Monitoring
4 (1)(d) Monitoring and testing include evaluation of closure welds, fabrication defects, and post-fabrication damage, in particular damage that may occur during handling operations; and	3.3.4 Monitoring and Testing of Waste Packages

Table 2-2. Correlation of the Provisions from Section 2.4.3 of the Yucca Mountain Review Plan, Final Report, Performance Confirmation Program-Acceptance Criteria, and the Performance Confirmation Plan Sections (Continued)

YMRP Acceptance Criterion	Performance Confirmation Plan Section
4 (1)(e) The program is technically feasible, taking into consideration that the methods proposed are suitable and practicable and the sensors and devices to be used are either able to sustain the prevailing environmental conditions (e.g., temperature, humidity, radiation) during the required period of repository operation, or are replaceable.	5.0 Test Planning and Implementation
4 (2) The performance confirmation plan establishes a program of laboratory experiments that focuses on the internal condition of the waste packages. The environment experienced by the emplaced waste packages is duplicated in the laboratory experiments to the extent practicable. The laboratory experiments are adequate because:	3.0 Description of Performance Confirmation Activities 3.3.4.2 Corrosion Testing 3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples 3.3.4.4 Waste Form Testing
4 (2)(a) They provide data needed to design the waste package and confirm performance assessment models and assumptions; and	3.3.4 Monitoring and Testing of Waste Packages
4 (2)(b) Corrosion monitoring and testing include, but are not limited to, the use of corrosion coupons.	3.0 Description of Performance Confirmation Activities 3.3.4.2 Corrosion Testing 3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples 3.3.4.4 Waste Form Testing
4 (3) The schedule for the waste package program requires monitoring and testing to begin as soon as practicable. Monitoring and testing will continue as long as practical up to the time of permanent closure.	6.0 Schedule

Source: NRC 2003 (DIRS 163274)

3. DESCRIPTION OF PERFORMANCE CONFIRMATION ACTIVITIES

To complement the previous section, which described the NRC regulatory requirements and guidance applicable to this performance confirmation program, this section provides a detailed discussion of activities that meet those requirements. This section begins with a discussion that describes the relationships of the three barriers to the performance confirmation activities supporting the barrier analysis. The section then lists the 20 activities, grouped according to the four acceptance criteria categories cited in YMRP NUREG-1804 (NRC 2003 [DIRS 163274]). For each activity, the section provides a title, description, purpose, selection justification (both technical and regulatory), a current understanding of each activity, and the anticipated methodology for the test. The descriptions also provide, where available, citations to the documents containing reference data. The activity descriptions also identify whether the activity includes in situ monitoring, laboratory, or field methods and states the reason why the activity will not adversely affect the ability of the repository to meet performance objectives. Also, Section 4 provides complementary discussion including the approach to the development and handling of the performance confirmation program baseline information (preliminary baseline), including parameter measurements analysis and evaluation, and the reporting and recommendations (where appropriate) for corrective actions.

3.1 ACTIVITY SELECTION

The approach used for selecting the set of activities (measured parameters and data acquisition methods) important to evaluating the postclosure performance of the repository was based on three criteria and a decision analysis process described in Section 1.4.1. Table 1-1 provides the current list of the 20 activities selected for the performance confirmation program.

Many performance confirmation activities and tests described in this section were preceded by tests conducted during site characterization (see Sections 5 and 6). Site characterization testing developed information that was used in subsurface design, Engineered Barrier System design, and development of the process models used to support assessments of repository performance. Selected site characterization data along with the performance assessment provides the reference base for performance confirmation comparisons (Section 4.2). Testing begun during site characterization is only discussed to the extent that it is being continued as part of the current performance confirmation program.

The test methods included in the following test activity descriptions are intended to reflect the general approach and demonstrate one or more possible methods for attaining the purpose of each test. The descriptions will be modified as needed to support eventual implementation.

3.2 RELATIONSHIP OF THE BARRIERS AND ACTIVITIES

The repository system utilizes two natural barriers and one Engineered Barrier System (refer to Section 1.3.2) that have been characterized and designed to work together to prevent or reduce the movement of water, or prevent the release or substantially reduce the release rate of radionuclides. The repository system that forms these barriers includes features or structures, systems, and components (SSCs) that contribute to the performance of one of the three barriers and is considered to be relevant to waste isolation.

Table 3-1 summarizes the relationship between barriers, and models that are used to analyze performance of those barriers, and performance confirmation activities.

Table 3-1. Relationship between Barriers, Models, and Performance Confirmation Activities

Barrier	Models	Performance Confirmation Activities
Upper Natural Barrier	Infiltration model	Precipitation monitoring
	Unsaturated zone flow	Precipitation monitoring, subsurface water and rock testing, and unsaturated zone testing
	Ambient seepage	Seepage monitoring
	Thermal seepage	Seepage monitoring and thermally accelerated drift in-drift environment monitoring, and near-field environment monitoring
Engineered Barrier System	Drift degradation and rockfall	Drift inspection, construction effects monitoring, and thermally accelerated drift thermal-mechanical monitoring
	Thermal-hydrologic-chemical	Thermally accelerated drift near-field environment monitoring
	Thermal-hydrologic l	Thermally accelerated drift near-field environment monitoring
	In-drift physical and chemical environment	Thermally accelerated drift in-drift environment monitoring
	Drip shield degradation	Corrosion testing and corrosion testing of thermally accelerated drift samples
	Waste package degradation	Corrosion testing, dust buildup monitoring, corrosion testing of thermally accelerated drift samples, and waste package monitoring
	In-package water chemistry	Waste form testing
	Cladding degradation	Waste form testing
	Commercial spent nuclear fuel degradation	Waste form testing
	Defense spent nuclear fuel degradation	Waste form testing
	High-level radioactive waste glass degradation	Waste form testing
	Dissolved concentration limits	Waste form testing
	Colloid transport	Waste form testing and unsaturated zone testing
	Engineered Barrier System flow and transport	Waste form testing, dust buildup monitoring, thermally accelerated drift in-drift environment monitoring
Lower Natural Barrier	Unsaturated zone flow	Subsurface water and rock sampling, unsaturated zone testing
	Radionuclides transport in the unsaturated zone	Subsurface water and rock sampling, unsaturated zone testing
	Saturated zone flow	Saturated zone monitoring, saturated zone fault hydrology testing, saturated zone alluvium testing
	Saturated zone transport	Saturated zone monitoring, saturated zone fault hydrology testing, saturated zone alluvium testing

NOTE: Three performance confirmation activities do not directly relate to models, therefore are not included in this table. These activities are subsurface mapping, seismicity monitoring, and seal testing.

Table 3-2 provides a crosswalk to the proposed parameters and activities. The activities are grouped into the four acceptance criteria categories identified in the Section 2.4.3 of YMRP NUREG-1804, (NRC 2003 [DIRS 163274]) and are listed below under the sections that they principally support. For each activity the table gives a brief activity description and a summary of the candidate parameter(s) to be measured. The next column of the table defines the purpose of the activity in terms of how the data are to be used in the categories mentioned above. The last column of the table lists a reference to Section 3 where preliminary baseline information sources are provided for each activity.

The repository site (location and elevation) take advantage of the natural attributes of the geologic setting in general, and of the repository host rock, the Topopah Spring welded tuff hydrogeological unit (TSw), in particular. These attributes include:

- A semiarid climate with limited precipitation
- A thickness of rock and soil above the repository of approximately 215 to 450 meters (BSC 2003 [DIRS 166183])
- Hydrogeologic and geochemical characteristics that limit radionuclide movement
- Geologic and geomechanical characteristics that permit the design and construction of effective engineered barriers
- Geomechanical and thermal characteristics that allow maintenance of a stable facility with adequate capacity for waste disposal
- Absence of significant faults within the disposal area
- Depth to groundwater below repository emplacement drifts from more than 215 meters to nearly 365 meters (BSC, 2003 [DIRS 165802]).

The repository system includes three distinct barriers to the movement of water and the mobilization and movement of radionuclides. Some of these barriers are mutually reinforcing, such that if a barrier does not perform as expected, the performance of the other barriers can provide adequate safety. For example, if the Engineered Barrier System (drip shield, waste package, and cladding) is degraded or disrupted, the Upper Natural Barrier will continue to limit water contact, and the Lower Natural Barrier will continue to limit radionuclide mobilization and movement.

Table 3-2. Performance Confirmation Activity Description and Relationships to Performance Assessment Parameters, Purpose, and Section Containing Detailed Discussion and Baseline Information

ACTIVITY	ACTIVITY DESCRIPTION	CANDIDATE PARAMETERS	PURPOSE	DISCUSSION / BASELINE INFORMATION
General Requirements Testing and Monitoring (Natural and Engineered Barriers)				
Precipitation monitoring	Monitoring of precipitation and composition analysis.	Precipitation rate, quantity, and chemical composition.	To evaluate the precipitation input parameter that relates to seepage modeling.	Section 3.3.1.1
Seepage monitoring	Seepage monitoring and laboratory analysis of water samples (from bulkheaded alcoves on the intake side of the repository and in thermally accelerated drifts).	Seepage rate, locations, quantity and chemical composition, ventilation air barometric pressure, ventilation air temperature, ventilation air relative humidity.	To evaluate results from the seepage model.	Section 3.3.1.2
Subsurface water and rock testing	Laboratory analysis of chloride mass balance and isotope chemistry based on samples taken at selected locations of the underground facility.	Chloride mass balance; 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.	Section 3.3.1.3
Unsaturated zone testing	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 the unsaturated zone model.	Section 3.3.1.4
Saturated zone monitoring	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.	Section 3.3.1.5
Saturated zone fault hydrology 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.	Section 3.3.1.6

Table 3-2. Performance Confirmation Activity Description and Relationships to Performance Assessment Parameters, Purpose, and Section Containing Detailed Discussion and Baseline Information (Continued)

ACTIVITY	ACTIVITY DESCRIPTION	CANDIDATE PARAMETERS	PURPOSE	DISCUSSION / BASELINE INFORMATION
Saturated zone alluvium testing	Tracer testing at the Alluvial Test 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 models.	Section 3.3.1.7
Drift inspection	Regular inspection of nonemplacement drifts and periodic inspection of emplacement drifts, thermally accelerated drifts, 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, both within emplacement drifts and nonemplacement drifts, and rockfall size or probability distributions. Also supports confirmation of retrievability.	Section 3.3.1.8
Thermally accelerated drift near-field monitoring	Monitoring of near-field coupled processes (thermal-hydrologic-mechanical-chemical) properties and parameters associated with the thermally accelerated drifts.	Rock-mass moisture content, temperatures, air permeability (fracture permeability), mechanical deformation, mechanical properties, water chemistry.	To evaluate coupled process results from the thermal-hydrologic-chemical-mechanical models.	Section 3.3.1.9
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.	Section 3.3.1.10
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 a thermally accelerated drift.	Temperature, relative humidity, gas composition, radionuclides, pressure, and radiolysis, thin films evaluation, condensation water quantities and composition or ionic characteristics including microbial effects.	To evaluate assumptions used in in-drift physical and chemical environment models.	Section 3.3.1.11

Table 3-2. Performance Confirmation Activity Description and Relationships to Performance Assessment Parameters, Purpose, and Section Containing Detailed Discussion and Baseline Information (Continued)

ACTIVITY	ACTIVITY DESCRIPTION	CANDIDATE PARAMETERS	PURPOSE	DISCUSSION / BASELINE INFORMATION
Geotechnical and Design Monitoring and Testing				
Subsurface mapping	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 integrated site models	Section 3.3.2.1
Seismicity monitoring	Monitoring regional seismic activity. Observation of subsurface and surface (large magnitude) fault displacement after significant local or regional seismic events.	Event detection, event magnitude, event location, strong-motion data collection and analysis, seismic attenuation investigations (within 50 kilometers).	To evaluate annual probability distribution as a function of intensity.	Section 3.3.2.2
Construction effects monitoring	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.	Section 3.3.2.3
Thermally accelerated drift thermal-mechanical monitoring	Monitoring drift and invert shape and integrity in a 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 under thermal conditions.	Section 3.3.2.4
Design Testing (Other Than Waste Packages)				
Seal 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 seals materials, configuration, performance; shaft seals materials configuration, performance; ramp seals materials, configuration, performance; laboratory and field hydraulic and pneumatic seal effective permeability.	To evaluate design assumptions for effective seals.	Section 3.3.3.1

Table 3-2. Performance Confirmation Activity Description and Relationships to Performance Assessment Parameters, Purpose, and Section Containing Detailed Discussion and Baseline Information (Continued)

ACTIVITY	ACTIVITY DESCRIPTION	CANDIDATE PARAMETERS	PURPOSE	DISCUSSION / BASELINE INFORMATION
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 waste package integrity and confirm the absence of leakage and leak paths.	Section 3.3.4.1
Corrosion testing	Corrosion testing in the laboratory of waste package, waste package 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.	Alloy 22, Type 316 stainless steel, and titanium alloys (Grade 7 and 24) mass loss rate, passive current density, surface dissolution, open circuit potential, critical potential, stress crack corrosion, microbial effects, surficial passive film stability, and mechanical properties.	To evaluate results of corrosion models.	Section 3.3.4.2
Corrosion testing of thermally accelerated drift samples	Corrosion testing in the laboratory of waste package, waste package pallet, and drip shield samples exposed to conditions in the thermally accelerated drifts. Includes corrosion model applicability and laboratory testing of general corrosion, phase transformations of Alloy 22; and localized corrosion	Thermally accelerated drifts exposed Alloy 22, Type 316 stainless steel, and Titanium alloy (Grade 7 and 24) mass loss rate, passive current density, surface dissolution, open circuit potential, critical potential, stress crack corrosion, microbial effects, surficial passive film stability, and mechanical properties.	To evaluate results of corrosion models.	Section 3.3.4.3
Waste form testing	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, including cladding degradation, failure and unzipping rate, and waste form/waste package performance under coupled chemical environments.	To evaluate results of waste form degradation models and evaluate in-package expected conditions.	Section 3.3.4.4

NOTE: Cl = chlorine; Eh = electrochemical poten tial; H = hydrogen; I = iodine; O = oxygen; pH = hydrogen potential; Q = Norwegian Geotechnical Institute Q-System Rating for Rock Mass Classification; RMR = Geomechanics Classification Rock Mass Rating System; Sr = strontium; Tc = technetium; U = uranium.

Activities are grouped according to the four acceptance criteria in the YMRP NUREG-1804 (NRC 2003 [DIRS 163274]).

The effectiveness of the selected activities in meeting the objectives of the performance confirmation program is discussed in terms of three barriers that limit radionuclide release, and water and radionuclide movement. The three primary barriers (with their corresponding features and SSCs) associated with the performance confirmation activities are:

- Upper Natural Barrier
  - Topography
  - Soils
  - Unsaturated zone of rock (which includes the repository horizon).
- Engineered Barrier System
  - Waste forms
  - Cladding
  - Waste packages
  - Waste package pallets
  - Drip shields
  - Emplacement drift inverts
  - Emplacement drifts
  - Emplacement drift closures.
- Lower Natural Barrier
  - Unsaturated zone rock below the drifts
  - Saturated zone (consisting of rock, and alluvium).

The Upper Natural Barrier operates as a barrier because the surface topography, soils, and bedrock limit water infiltration. Moreover, the unsaturated rock layers above the repository horizon and the drift opening further limit water flux into the repository emplacement drifts. The primary large-scale processes contributing to this capability are:

- Lateral diversion of percolating water

- Damping of episodic pulses of precipitation and infiltration

- Capillary forces limit seepage into the emplacement drift

- Limitation of seepage because of elevated temperatures in the rock

- Limit flow of water in possible fast paths (if present they represent a small fraction of total percolation flux, limited by properties of the Upper Paintbrush non-welded vitric (PTn).

The Engineered Barrier System performs because the waste package (protected from rockfall damage by drip shields) limits water contacting the waste form, coupled with cladding that limits water contacting the waste matrix, followed by the waste form that limits rate of release of radionuclides. Finally, the drift invert further limits the rate of release of radionuclides to the Lower Natural Barrier.

The Lower Natural Barrier performs because the unsaturated rock layers below the repository horizon limit radionuclide transport to the saturated zone. The tuff and alluvial aquifers further limit radionuclide transport in the saturated zone.

The repository system utilizes natural and engineered barriers that have been selected (natural barrier systems) and designed (Engineered Barrier System) to work together to isolate waste. The capability of each barrier depends upon the physical processes that contribute to performance. Physical features of each barrier system contribute to performance and can be grouped and evaluated independently, such as precipitation (the expected maximum input of water to the system), or a geologic feature, an engineered structure, a waste package, or a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides. Engineered barriers may also include material placed over and around the waste. The capability of barriers is measured by their ability to prevent or substantially reduce the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevent the release or substantially reduce the release rate of radionuclides.

Upper Natural Barrier–The natural features of Yucca Mountain include the rock above and the rock below (i.e., hydrologically downstream of) the repository. The rock above the repository consists of the surface soils and the unsaturated zone features, which together limit the rate and volume of water reaching the Engineered Barrier System. The performance of the rock above the repository will be measured by monitoring precipitation (i.e., the input to water movement through the features) and seepage.

By limiting water movement to the emplacement drifts, the Upper Natural Barrier limits the release of solubility-limited radionuclides such as the isotopes of plutonium and neptunium. The performance of this barrier can be evaluated by seepage measurements. If seepage occurs, data interpretation requires a history of the temporal and spatial patterns of precipitation for periods prior to the seepage event. These data collection activities, started during site characterization, will continue during performance confirmation. The other performance confirmation activity associated with the Upper Natural Barrier is the seal testing activity required by 10 CFR 63.133(a) and (d). It evaluates the effectiveness of ramp, borehole, and shaft seal designs. Ramp, borehole, and shaft seal testing (Section 3.3.3.1), will be conducted to ensure that these penetrations do not circumvent the functions provided by surface soils and the unsaturated zone above the repository. The activity is to ensure that the repository penetrations do not create a hydrologic short circuit of the surface and unsaturated zone above the repository barriers.

A small fraction of the precipitation percolates through the rock to the repository horizon, and even a smaller fraction can overcome the drift wall capillary effect to seep into the waste emplacement drift. Seepage refers to the water that drips into the drift. The seepage (Section 3.3.1.2) is therefore, the amount of water reaching the Engineered Barrier System. 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 unventilated thermally accelerated drifts to detect thermally driven seepage into a heated and unventilated drift which represent conditions most typical of the postclosure repository during its compliance period. Observations of subsurface conditions (Sections 3.3.1.3 and 3.3.1.4), will confirm that the physical conditions and assumptions used in the models are actually the conditions encountered in the repository.

The thermal-mechanical-hydrologic-chemical environment within the emplacement drifts affects the performance of the engineered features. Consequently, some performance confirmation activities during the construction of the repository (Section 3.3.2.3) are designed to evaluate assumptions and data that influence the in-drift environments. Existing data are based in large measure on prior construction of the Exploratory Studies Facility (ESF).

Actual subsurface conditions from site characterization excavations will be confirmed by mapping of emplacement drifts and mains. The mapping activity includes fractures and faults, stratigraphic contacts, and lithophysal characteristics. Mechanical properties will be measured and confirmed based on deformation just after construction. Water samples will be obtained from the rock, and the water chemistry and age will be assessed using chloride mass balance and isotope chemistry (Section 3.4.3.1.3). Monitoring of host rock near-field coupled processes (e.g., moisture content, fracture permeability, temperatures and thermal gradients, mechanical properties and deformations, water chemistry data) will be accomplished using boreholes from an observation drift or from alcoves located near a thermally accelerated drift (Section 3.4.3.1.9).

Temperature evolution during the postclosure period is important to simulate during the operational period, because degradation of the waste packages is subject to the temperature dependent, long-term environmental conditions. Data and insight into anticipated postclosure conditions in the repository will be obtained during the preclosure period using thermally accelerated drifts. Performance confirmation activities addressing the environment in thermally accelerated drifts include temperature measurements and tests, humidity, dust composition, gas composition, pressure, radiolysis effects, condensate chemistry, thin film chemistry, and microbes (Section 3.4.4).

The heat added to the underground facility due to decay of the radioactive waste will result in elevated temperatures for long periods, and the elevated temperatures can influence coupled processes in the drifts and in the surrounding near-field rock. These processes couple heat flow, hydrology, chemistry, and mechanical stability. Measurements of these characteristics began during site characterization, focusing on the nonlithophysal rock units. Because the waste will also be emplaced in lithophysal rock units, evaluation of design and performance assessment assumptions and analyses in the lithophysal rock will be obtained in thermally accelerated drifts activities.

Engineered Barrier System–The Engineered Barrier System is composed of SSCs designed to work together and to complement the natural barriers system in isolating waste from the environment. As shown in Figure 1-2, the Engineered Barrier System consists of several features that contribute to waste isolation, including: (1) drip shields that keep water and rockfall away from the waste packages; (2) long-lived waste packages that isolate the waste forms from the in-drift environment; (3) corrosion-resistant waste forms and cladding on spent nuclear fuel that limits water contact with the waste form and release of radionuclides from a breached package; (4) solid waste forms that degrade and release radionuclides slowly; (5) waste package pallets; (6) the granular emplacement drift invert, beneath the waste package that delay the diffusive release of radionuclides; (7) emplacement drifts; and (8) emplacement drift closures to limit releases in the unlikely event of igneous activity.

Potential causes of a breach of a waste package include corrosion or mechanical failure due to ambient, thermally induced, or seismically induced rockfall. Accordingly, some activities directly monitor conditions that could lead to degradation of the waste package, and thus to mobilization of the waste form. Selected emplacement drifts will be periodically inspected for unlikely occurrences of rockfall, sagging ground supports, changes in package positions and drift stability due to seismic events, as well as invert degradation (Section 3.3.1.8) to ensure that designed systems are operating as anticipated. In the thermally accelerated drift, drift shape and thermal seepage will be monitored to evaluate assumptions concerning thermally induced natural system changes (Section 3.3.1.9).

A substantial portion of the performance confirmation program is related to the Engineered Barrier System, specifically the waste package degradation mechanisms because, during the compliance period, the waste package in the environment created by the natural systems isolates radionuclides from the accessible environment.

For further understanding, representative waste packages will be monitored in situ (Section 3.3.4.1). A number of performance confirmation activities address the mechanistic details of the corrosion processes to assess whether the measured waste package and drip shield corrosion rates are as anticipated (Section 3.3.4.2 and Section 3.3.4.3). In general, these activities continue work begun during site characterization for each potential degradation mode of a waste package. The activities are extended to include samples exposed in the laboratory under a range of potential repository thermal and chemical environments, and samples exposed in one or more thermally accelerated emplacement drifts.

Waste form testing evaluates anticipated chemical and physical changes in waste forms. This evaluates assumptions made about the availability of radionuclides from the waste form (Section 3.3.4.4). The Project will also evaluate whether conditions can be created within intact packages that would cause the waste package to corrode from the inside out (waste package, waste form coupled effects). The cladding, the waste form, and the drift invert also limit annual dose at the accessible environment.

Lower Natural Barrier–The rock below the repository consists of the unsaturated zone and saturated zone features. The saturated zone includes both tuff and alluvium along the 18-kilometer distance to the regulatory compliance point.

The Lower Natural Barrier is important in reducing the annual dose at the accessible environment for radionuclides with short half-lives (e.g., cesium and strontium) and for solubility-limited radionuclides (e.g., neptunium and plutonium). The mapping and supporting activities described above will support assessment of flow characteristics of the unsaturated zone. In addition, transport and sorption properties of the Lower Natural Barrier unsaturated zone will be evaluated by in situ tests conducted in the repository horizon as a surrogate for the properties of the unsaturated zone rock below the repository (Section 3.3.1.4). The saturated zone activities include chemistry (affects retardation), colloids, and water level and fault zone hydrologic characteristics (useful for evaluating flow paths and rates).

Overall performance will be evaluated by monitoring radionuclide content in wells located in the saturated zone upgradient, beneath, and downgradient from the repository. Because of the expected lack of a radionuclide source term and the expected long transport duration the most likely result of this activity is that no elevated radionuclide content in the saturated zone water is found.

For the unsaturated zone, transport and sorption properties will be tested in an ambient seepage alcove or drift containing no emplaced waste packages, in order to provide information to evaluate unsaturated zone transport models results (Section 3.3.1.4). For the saturated zone, performance confirmation activities will monitor the water levels and water chemistry to evaluate overall assumptions and data about saturated zone flow as well as behavior of radionuclides (Section 3.3.1.5). Fault zones within the saturated zone provide the potential for faster flow rates and preferential flow paths; therefore, testing of the hydrologic characteristics of a fault zone is included to confirm flow paths and rates (Section 3.3.1.6). The performance confirmation program also includes tracer testing in the Alluvial Test Complex using multiple boreholes to evaluate transport of radionuclides in the saturated zone (both dissolved and colloidal transport) (Section 3.3.1.7).

In addition to these location-based barriers, this *Performance Confirmation Plan* includes a discussion on thermally accelerated drifts, which involves both natural and engineered features, and activities associated with disruptive events and the waste form itself.

Representativeness of Samples and Conditions for Testing–Waste package testing performance confirmation activities are to demonstrate that they are monitoring or testing representative samples in representative locations consistent with YMRP NUREG-1804 (NRC 2003, [DIRS 163274] Section 2.4.1).

The corrosion coupons (test samples) currently in the long-term corrosion facility are representative of waste package and drip shield materials (same materials as in the design), including processes used to fabricate, assemble, weld, and stress relieve these materials. Future samples will be obtained from representative waste packages procured to hold waste at the repository and will include material having undergone the weld and stress relief processes. Waste packages selected for underground monitoring will be representative of different configurations as well as different environmental conditions that may exist underground such as in areas with differing rock properties (i.e., thermal conductivity or fracture density) and location within the drifts (e.g., near the ventilation entrance as well as the ventilation exit to investigate differences related to temperature and humidity variations, as well as proximity to hotter or cooler packages) (Section 3.3.4.1).

Thermally Accelerated Drift Test Facility–The interactions of the Upper and Lower Natural Barriers and the Engineered Barrier System during the elevated thermal period are an important part of the performance confirmation program. DOE has chosen to develop a field test complex specifically to address these interactions. Because this test bed has a high level of complexity, investigates coupled processes, and represents a large contribution to the performance confirmation program, it is discussed in a separate section (Section 3.4.5). To examine the effects of the long-term postclosure environmental conditions on repository performance, one or more emplacement drifts will be thermally accelerated by a blend of ventilation control and waste package loading. These thermally accelerated drifts are normal emplacement drifts that are strategically loaded with waste packages to ensure a prescribed thermal load. The thermally accelerated drift testing simulates postclosure temperatures, while reducing the postclosure boiling to subboiling transition time period to approximately fifty years, in order to observe in-rock and in-drift thermal-hydrologic-mechanical-chemical coupled processes during the operational period. In addition, waste packages will be closely monitored, and samples of engineered barrier materials will be placed to allow the study of potential corrosion mechanisms in a realistic in situ environment.

For the proposed concept of two thermally accelerated drifts within the underground facility, each accelerated drift begins in the middle nonlithophysal unit, and the dip of the stratigraphic units will result in transition into the lower lithophysal unit about one third of the way into the drift. The observation drift will be at a lower elevation than the two heated drifts; it will also be in a pillar between drifts rather than directly below a heated drift to reduce thermal interference. Alcoves and boreholes from the observation drift will be used to position instruments in the near-field rock, which will allow maintenance of the instruments without entering the heated drifts. Remote methods will be evaluated (not as part of performance confirmation) that can access the accelerated drifts to retrieve samples, inspect waste packages, measure changes to the drift shape, and measure the evolution of the environment, including observation of seepage, if any, and the locations and intensity of condensation during cooling.

The technology to remotely detect and measure anticipated parameters in bulkheaded alcoves is available. However, high-temperature and high-radiation environments representative of postemplacement conditions in thermally accelerated drifts will require development of specific remote monitoring applications.

3.3 PERFORMANCE CONFIRMATION ACTIVITIES

For purposes of presenting planned activities, summary activity descriptions are provided in the following sections. The order of presentation is in accordance with major headings of 10 CFR Part 63, Subpart F and the YMRP NUREG-1804 (NRC 2003, [DIRS 163274] Section 2.4.3) (see Section 2).

Each activity is identified by a name, an activity description, purpose, selection justification (both technical and regulatory), current understanding for that activity, and anticipated methodology that may be appropriate to test and monitor parameters in that activity. The summary introduction lists the major parameters that may be measured or tested, the barrier that the activity investigates, when testing and monitoring began or are anticipated to begin, and other programs that may support interpretations.

The purpose, selection justification, current understanding, and potential methodologies are discussed. The selection justification contains a tie to the appropriate part of the regulation and states why this is the appropriate activity to evaluate barrier performance. The current understanding describes in summary manner what is known about the parameters covered by this activity, the location of the baseline, and an assessment of the potential impacts on waste isolation as a result of this activity, recognizing that an activity specific evaluation will be conducted during test planning. Currently LP-SA-001Q-BSC, *Determination of Importance and Site Performance Protection Evaluations* ([DIRS 158528]) establishes the process and responsibilities for evaluating activities for adverse impacts and establishing appropriate quality assurance controls to prevent or minimize such potential impacts at the Project site.

The anticipated test methodologies are only examples of those that were used in the decision analysis (see Section 1) to evaluate feasibility and suitability of the parameters to satisfy the performance objectives. These methodologies are only examples of potential techniques and methods that may be used. The PC Test Plans (further described in Section 5) developed later during the detailed test planning will provide detailed discussion.

Eleven performance confirmation activities and tests described in this section were begun during site characterization:

- Precipitation monitoring
- Seepage monitoring
- Subsurface water and rock testing
- Unsaturated zone testing
- Saturated zone monitoring
- Saturated zone alluvium testing
- Subsurface mapping
- Seismicity monitoring
- Construction effects monitoring
- Corrosion testing
- Waste form testing.

Site characterization testing developed parameters for subsurface design, the Engineered Barrier System design, and for the initial assessments of repository performance. Prior testing is not discussed further, except where the individual test activity descriptions refer to the prior tests. Two new tests will be initiated during construction, and seven new tests will be initiated during operations. The further that the tests are projected into the future, the less about their design, methodologies, and specific parameters is discussed at this time.

The test methods included in the following test activity descriptions are intended to reflect the general approach and demonstrate one or more possible methods for attaining the purpose of each test. The descriptions will be modified as needed in PC Test Plans to support eventual implementation. Advances in technology can be expected to occur by the time many of these activities are fielded. Therefore, this performance confirmation program must remain flexible, with a process using PC Test Plans, to reevaluate, reexamine, and modify the activities to consider the current state of technology and understanding. In some cases, the actual set of activities may change as new tests are needed, or as influenced by new technologies.

3.3.1 General Requirements Testing and Monitoring (Natural and Engineered Barriers)

In response to 10 CFR 63.131(a)(2), the performance confirmation program is directed at monitoring and testing to evaluate if natural and engineered systems and components designed or assumed to operate as barriers after permanent closure are functioning as intended, as described below and in Section 3. Performance confirmation program activities are designed to provide data that evaluate, where practicable, the ability of natural systems and engineered SSCs assumed to operate as barriers after permanent closure to serve their intended and anticipated functions.

The function of the Upper Natural Barrier is to reduce the rate of water movement into the rock mass below. The ability of the surface barrier to limit water movement will be addressed by monitoring of precipitation and seepage. Results from the program will be used to assess the joint capabilities of the topography, surficial soils, and the unsaturated rock features above the repository to limit the amount of water that seeps into the drifts. The ability of the unsaturated zone above the repository barrier to limit water movement will be addressed by monitoring seepage into bulkheaded alcoves, thermally accelerated drifts and emplacement drifts, and by collection of seepage water found. If seepage occurs, water samples will be analyzed for chemical constituents to provide additional data to help evaluate the results from in-drift environment models. The chemistry of water in the unsaturated zone adjacent to emplacement drifts across the repository will provide information to assess the percolation flux that influences seepage. This chemistry will also influence the in-drift environments.

The function of the Lower Natural Barrier includes both unsaturated and saturated zone rocks and alluvium below the repository. The function of the unsaturated zone is to limit the rate of transport of radionuclides from the invert to the saturated zone beneath the repository. The retardation effect of the unsaturated zone on the radionuclide movement is radionuclide specific. The performance confirmation program will monitor saturated zone wells upgradient and downgradient of the repository, testing the joint capability of the unsaturated zone below and the saturated zone barriers to limit radionuclide transport. The program will monitor any changes in background sources from the Nevada Test Site to evaluate if radionuclides are released from the Engineered Barrier System. The chemistry in the unsaturated zone will provide information to assess the percolation flux that influences transport. This chemistry will also directly influence the transport of radionuclides in the near-field rock.

The function of the saturated zone is to reduce the rate of radionuclide transport from the repository to the accessible environment. Similar to the unsaturated zone barrier below the repository, the retardation effect of the saturated zone on radionuclide movement is radionuclide specific. The capability of the saturated zone barrier to limit radionuclide movement will be addressed directly by a program of monitoring saturated zone wells upgradient, under, and downgradient from the repository for water levels, chemistry, and radionuclide content. Properties of the alluvium will be evaluated with cross-hole tracer testing. Additional activities that indirectly address the capability of the saturated zone barrier include testing of fault zone hydrologic and transport characteristics.

Activities designed principally to provide information relevant to these functions include:

- Precipitation monitoring (Section 3.3.1.1)
- Seepage monitoring (Section 3.3.1.2)
- Subsurface water and rock testing (Section 3.3.1.3)
- Unsaturated zone testing (Section 3.3.1.4)
- Saturated zone monitoring (Section 3.3.1.5)
- Saturated zone fault hydrology testing (Section 3.3.1.6)

- Saturated zone alluvium testing (Section 3.3.1.7)
- Thermally accelerated drift near-field monitoring (Section 3.3.1.9).

Performance confirmation program activities are designed to provide data to evaluate, where practicable, intended and anticipated performance. Rockfall monitoring in the underground facility will be conducted by drift inspection. The thermally accelerated emplacement drifts will be monitored for drift degradation through changes in shape as well as the in-drift environment conditions to ensure that the testing environments are comparable to the actual conditions in the emplacement drifts. In-drift condition monitoring includes dust buildup and composition, which could facilitate corrosion. Condensation water quantities, composition, and ionic characteristics will be monitored remotely in a thermally accelerated emplacement drift.

Activities designed principally to provide information relevant to these performance objectives are:

- Drift inspection (Section 3.3.1.8)
- Dust buildup monitoring (Section 3.3.1.10)
- Thermally accelerated drift in-drift environment monitoring (Section 3.3.1.11).

To accomplish the performance confirmation objectives for these activities, thermally accelerated drift testing will provide insight into the postclosure response of the repository to expected thermal loads. The intent is to develop thermal environments in normally constructed emplacement drifts in which representative postclosure coupled thermal, hydrologic, mechanical, and chemical processes as well as microbial and radiological effects can be monitored and observed. Planning for these activities is preliminary in nature; other methods and approaches may be employed and will be described in the PC Test Plans.

Activities are planned in thermally accelerated drifts to monitor in-drift conditions, expose samples of Engineered Barrier System materials to potential corrosion mechanisms in representative in situ environments, monitor drift degradation, and test near-field coupled processes (Section 3.4.5). The conceptual test design includes plans for two thermally accelerated drifts and an observation and instrumentation drift at a lower elevation. Completion of the instrumentation and baseline measurements of the two accelerated drifts will be accomplished as early as practicable during waste emplacement activities.

3.3.1.1 Precipitation Monitoring

Activity Description–This activity includes precipitation monitoring and analysis of precipitation composition. Precipitation represents the maximum input of water to the Upper Natural Barrier. Candidate parameters that may be measured include: precipitation rate, quantity, and chemical composition. This is a long-term field collection activity providing a direct measurement of the parameters. Precipitation monitoring began during site characterization and will continue until closure. Meteorological monitoring, in conjunction with this performance confirmation activity, is also expected to support the environmental safety and health compliance program.

Purpose–The purpose of this activity is to evaluate the precipitation input parameter that relates to seepage modeling. This activity includes testing and monitoring to evaluate the results and assumptions of conceptual and numerical models used to describe the hydrologic conditions at Yucca Mountain. Precipitation quantity, distribution (i.e., spatial and temporal), and hydrochemistry will be monitored to assess and extend the precipitation and hydrochemistry record at the site. It will also provide for a comparison with seepage data. The Upper Natural Barrier contributes to waste isolation by limiting the amount of water available to contact the Engineered Barrier System and by establishing the physical and chemical environment that contributes to the long life of the Engineered Barrier System. As shown in Figure 1-1, infiltration into the Upper Natural Barrier is limited through a combination of low precipitation, evapotranspiration, and runoff. This activity directly addresses the performance of the Upper Natural Barrier because precipitation serves as the maximum input of water to the repository system from the environment.

Selection Justification–This activity was selected because it directly addresses one of the bases for evaluating the performance of the Upper Natural Barrier and the requirements of the regulations. Precipitation serves as the maximum input of water to the repository system from the environment. As such, this activity is important to understanding seepage monitoring activities, and understanding input and output values of the process that carries water from the surface, through the unsaturated zone, and potentially down into the emplacement drifts. Information obtained from precipitation monitoring will be used as input to the unsaturated zone flow model for the evaluation of other quantities potentially important to repository performance (e.g., seepage time histories).

If the trends measured in the related seepage monitoring activities exceed the predicted ranges, the precipitation data will be used in the evaluation of those seepage measurements. Precipitation is the most significant environmental factor controlling net infiltration at Yucca Mountain (BSC 2003, [DIRS 165991] Table 6-8). The results from the risk-informed, performance-based activity selection approach described in Section 1.4.1 indicate high confidence that the measurements represent the temporal and spatial scale over the area of the repository during the preclosure measurement period. There is confidence that the modeled range of this parameter will not be exceeded during the measurement period. This activity is a relatively straightforward continuation of an existing activity to confirm the precipitation input parameter for the seepage model, placing seepage measurements in context.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2). Specifically, that the performance confirmation program must provide data that indicate, where practicable, whether natural 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.

Current Understanding–Precipitation monitoring is conducted currently at 29 operating precipitation-monitoring stations in the field for evaluating the record at Yucca Mountain. Stations record precipitation and other meteorologic data as they occur. Measurement recording is equipment specific, but usually recording is done every number of minutes (for electronically measured parameters such as temperature) or recording of a certain volume over time in the case of tipping buckets (during an event). Storage gauges total the precipitation received since the last time they were serviced. Office activities include obtaining meteorologic and climatic data collected by others from surrounding areas for comparison with the local Yucca Mountain record. This includes evaluating the statistical basis for the evaluation of fluctuations and extreme events that might affect infiltration, percolation, seepage, and transport.

Data collected will be used to evaluate precipitation inputs in support of the process model abstraction. The current performance assessment model simulates climatic change by using three separate distributions at different times in the compliance period. Table 3-3 compares estimates of annual precipitation for the present-day climate scenarios, representing conditions estimated to prevail for approximately the next 600 years.

Table 3-3. Estimated Precipitation for the Modern Climate Scenarios

Modern Climate Scenarios		Lower Bound (mm/year)	Mean (mm/year)	Upper Bound (mm/year)
Annual precipitation	Average	185.8	188.5	265.6
	Maximum	282.2	281.8	397.1
	Minimum	148.0	147.4	207.8

Source: USGS 2003, [DIRS 166518] Table 6-8; DTN: GS000308311221.005 [DIRS 147613]

Table 3-3 summarizes the average, maximum, and minimum annual precipitation rates for three present-day climate scenarios: a lower-bound scenario, a mean scenario, and an upper-bound scenario. It is not expected that the precipitation monitoring during the construction or operations period will deviate significantly from the present-day (modern) climate ranges. Table 3-3 will serve as the initial basis for comparison with performance confirmation data (Section 4.1). Trends will be treated as described in (Sections 4 and 4.2).

Anticipated Methodology–This activity includes long-term monitoring and laboratory analysis of selected water samples. Precipitation monitoring at Yucca Mountain presently uses two types of precipitation gauges. The first type is a tipping bucket gauge that defines the temporal nature of the events. The tipping bucket gauge, funnel, and rocker mechanism records the precipitation event as a cumulative number of 0.01-inch events and records the time they occurred. The second type of precipitation gauge is a storage gauge that consists of a large can, a funnel, and a measuring tube. Although this second type provides only a composite (total) precipitation amount it provides a confidence check for the tipping bucket gauge and will provide the water for the chemical analysis.

The precipitation-monitoring stations at Yucca Mountain are described in the *Yucca Mountain Site Description* (BSC 2004, [DIRS 169734] Section 6). Some are tipping bucket gauge and a storage gauge (BSC 2003 [DIRS 163158]). Others are equipped with tipping bucket gauges but no storage gauges. Because some of the chemical tests require larger volumes of water, the storage gauge is an ideal sample system; the size of the funnel can be increased if additional sample volume is required. Problems with snow and ice are dealt with by use of heating elements in the tipping bucket gauge and liquid antifreeze in the storage gauge. Because the precipitation monitoring activities will be conducted for an extended period, updates to the equipment, sampling program, and methodologies are expected (Brandt 2004 [DIRS 170246]).

The testing data are typically evaluated as an annual or seasonal range of precipitation and moisture conditions. A limit on the amount of precipitation would be established based on historical data, future climate assumptions, and the sensitivity of performance assessment models. If the precipitation exceeded a predetermined limit, or was increasing at a rate that may cause it to exceed expected ranges during the postclosure period, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity will not adversely affect the ability of the repository to meet performance objectives because the monitoring is noninvasive and occurs at the surface. Additionally, precipitation-monitoring activities do not result in the introduction of materials with chemical compositions that could transport through the natural system and affect the performance of the repository. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.2 Seepage Monitoring

Activity Description–This activity includes seepage monitoring, and laboratory analysis (from bulkheaded alcoves on the intake side of the repository and in the thermally accelerated drifts). Candidate parameters that may be measured include: seepage rate, locations and quantity; chemical composition; ventilation air temperature, humidity, and pressure. It represents the output of water from the Upper Natural Barrier to the Engineered Barrier System. This long-term field collection activity provides a direct measurement of seepage quantity and chemistry, if present and able to be sampled. Seepage monitoring in sealed ambient condition alcoves and in the Enhanced Characterization of the Repository Block (ECRB) Cross-Drift began during site characterization and will continue to be expanded to new areas through closure. General observation of seepage (if any) will also be conducted in conjunction with drift inspections (Section 3.3.1.8).

Purpose–The purpose of this activity is to evaluate results from the seepage model. Results of this activity are used to assess: (1) the spatial and temporal distribution of seepage in the drift, and, if possible, obtain samples of the seepage water for chemical analysis; and (2) the impact of thermal loading on the spatial and temporal extent of seepage and on water chemistry. The Upper Natural Barrier contributes to waste isolation by limiting the amount of water available to contact the Engineered Barrier System and by establishing the physical and chemical environment that contributes to the long life of the Engineered Barrier System. Point atmospheric measurements of vent air for temperature, relative humidity, and barometric pressure will be collected to confirm input conditions to the unsaturated zone. As shown in Figure 1-1, the Upper Natural Barrier limits flow through the volcanic tuffs in the unsaturated zone above the repository. The primary large-scale processes contributing to this capability include:

- Lateral diversion of percolating water
- Damping of episodic pulses of precipitation and infiltration.

This activity is intended to evaluate the assumptions used in and results obtained from the conceptual and numerical models used to describe the hydrologic conditions at Yucca Mountain for flow in the unsaturated zone. In addition, this activity will obtain field observations that can be used to evaluate chemical models that also indicate flow in the unsaturated zone.

Selection Justification–While precipitation serves as the maximum input of water to the repository system from the environment, seepage represents the output from the Upper Natural Barrier as it enters the Engineered Barrier System. As such, this activity evaluates the expected results of the infiltration, unsaturated zone flow in the rock above the repository, and seepage into drift models.

Deep percolation rates above the repository directly influence water seepage into the drifts and the amount of water entering breached waste packages, which, in turn, facilitates the release of radionuclides from the Engineered Barrier System into the unsaturated zone underlying the repository horizon. Because of drift wall capillary diversion, the ambient seepage model suggests that only a small fraction of the percolating water will reach the Engineered Barrier System components. The repository thermal pulse also affects seepage into drifts. A combination of ambient percolating and refluxed water may penetrate back along preferential flow paths into the thermally perturbed rock, that has temperatures above boiling, and seep into the drifts.

Information obtained from seepage monitoring will be used as input to models to determine the chemistry of water contacting engineered components. Seepage water chemistry can induce degradation of those components through aqueous corrosion processes.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, there is confidence that the modeled range of this parameter will not be exceeded and that a change in the parameter value greater than that currently used as the range in the performance assessments would likely change the selected conceptual models or require consideration of additional conceptual models. Therefore, this activity evaluates the seepage assumptions and expected values. This long-term field collection activity provides a direct measurement of seepage quantity and chemistry if present and able to be sampled.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(1) and (2); 10 CFR 63.132(a), and (b); and 10 CFR 63.133(a). Specifically, the performance confirmation program must provide data that indicate, where practicable, whether 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 whether natural 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. During repository construction and operation, a continuing program of surveillance, measurement, and testing, must be conducted to ensure that geotechnical and design parameters and design assumptions are confirmed. During the early or developmental stages of construction, a program for testing of the unsaturated zone must be conducted.

Current Understanding–The rock above the repository of the Upper Natural Barrier limits the movement of water through the unsaturated zone. Water flow in the fractured welded tuffs above the repository (the Tiva Canyon welded and the TSw hydrogeologic units that host the repository) occurs primarily in widely distributed fractures. In contrast, the PTn between the fractured welded tuffs is characterized by matrix-dominated flow. The transition from fracture to matrix flow tends to attenuate (dampen) flow pulse amplitude caused by variable infiltration and by lateral heterogeneity because of the distribution of fracture flow paths. This damping effect, both temporally and spatially, reduces the variability of percolation rates at depth. Geochemical data indicate that percolation rates at the level of the repository are relatively uniform. The unsaturated zone flow model is a comprehensive model based on an extensive field and laboratory testing program and is calibrated to match data and observations from pneumatic testing, water content (saturation) data, hydraulic-potential data, and geochemical and isotopic data.

Underground openings in unsaturated rock divert water around them because of the capillary barrier effect. Therefore, much of the water that percolates downward through the Yucca Mountain unsaturated zone will not seep into the drifts or reach Engineered Barrier System components. However, it is possible for the water potential in the rock formation to be higher than at the drift wall. When this occurs, water will exit the formation and enter the drift. At the drift surface, water can: (1) evaporate, (2) be transported as film flow down the wall, or (3) form a drop that eventually detaches becoming drift seepage. The impact of heat, generated by the decay of radioactive wastes, on drift seepage is of special interest. The hydrological and mechanical alteration of the rock physical parameters (i.e., permeability, porosity, moisture content, fracture interconnectivity) and the chemical evolution of waters, gas, and minerals are coupled to the thermal loading. Zones of boiling, condensation, and drainage are expected to influence the seepage distribution and water chemistry.

Models and analogue geologic data (BSC 2004, [DIRS 169218] Section 8) indicate that only a small fraction (less than about 10 percent) of drip shields and waste packages will experience any water flow in current climatic conditions. Even during wetter future climates, approximately one in three waste packages will be exposed to water seepage. The remainder will remain dry. The average seepage flux into emplacement drifts is about 25 percent of the percolation flux.

The design of the repository system uses the heat generated by emplaced waste to increase the diversion of percolating water and to further limit the amount of water available to seep into the emplacement drifts. As air temperature in the emplacement drifts exceeds the boiling point of water, liquid water will generally not be available to flow into emplacement drifts. Elevated temperatures will persist for several hundred to approximately 1,500 years following closure, depending on the specific location within the repository emplacement layout. To quantify and model the capillary barrier effect, associated seepage testing was conducted in ESF alcoves (Alcove 8) and niches (3107, 3566, 3650, 4788, and 1620) and at the Busted Butte Test Facility.

The seepage model considers the matrix and fracture hydrologic properties of the Topopah Spring Tuff and the design of the repository to evaluate the likelihood that seepage occurs. It incorporates the processes and conditions that evolve over time, including changes caused by the heat of the emplaced waste. Boiling of water dries the rock surrounding emplacement drifts and promotes the movement of water vapor away from the repository. The model is also used to evaluate the effect of the disturbed zone on seepage and on long-term performance of the repository when temperatures have declined to well below boiling.

The baseline information for this activity will be synthesized from TSPA-LA results as well as from information obtained from reports. Drift-scale seepage is modeled externally in the *Seepage Model for PA Including Drift Collapse* (BSC 2004 [DIRS 170000]) and the results are then abstracted as described in the *Abstraction of Drift Seepage* (BSC 2003 [DIRS 165564]), and then imported into the TSPA-LA model before performing the performance-assessment simulations.

Anticipated Methodology–Seepage monitoring and sampling will include, monitoring seepage occurrences and quantities, as well as conducting laboratory analyses of seepage fluids to confirm test results and evaluate model predictions. This work will be conducted using seepage alcoves or boreholes, as well as in thermally accelerated drifts. General observation of seepage (if any) will also be conducted in conjunction with drift inspections (Section 3.3.1.8). Seepage monitoring is intended to document the spatial and temporal distribution of seepage in the drifts (if it occurs) and, if possible, to obtain samples of the seepage water for chemical analysis. Additionally, it is intended to document the impact of thermal loading as it relates to the spatial and temporal distribution of seepage and water chemistry.

For the monitoring of inlet ventilation air characteristics, stations are currently located in the ESF and ECRB Cross-Drift consisting of barometric pressure transducers, humidity and temperature probes, wind speed sensors, and thermocouple psychrometers. These sensors are connected to data loggers, which in turn are connected to the underground fiber optic network for routine and remote data download. It is expected that a similar arrangement and test design will be employed for this performance confirmation activity.

Video systems will be installed in bulkheaded alcoves and monitored to identify potential seepage in the thermally accelerated drifts and bulkheaded alcoves (e.g., dark spots on the rock wall ground support, or wet spots on the drip shields). Humidity and temperature monitoring of the exit air in one thermally accelerated drift could be used as an indicator of seepage. Identification of humidity spikes or an abrupt temperature decrease in the exit air could be an indication of potential seepage. If spikes are noted, attempts will be made to investigate and recover samples.

To accomplish the performance confirmation thermal objectives for seepage monitoring, following the start of repository operations, thermally accelerated testing will be implemented by developing thermal environments in normally constructed emplacement drifts in which representative coupled thermal, hydrological, mechanical, chemical processes as well as radiological and microbial effects can be monitored. The thermally accelerated drifts concept is described in more detail in Section 3.4.5

Seepage monitoring and sampling in thermally accelerated drifts will test the impact of decay heat on drift seepage. The thermal-hydrologic-mechanical-chemical alteration of the permeability, porosity, moisture content, and fracture interconnectivity of the rock and the chemical evolution of waters, gas, and minerals are coupled to the thermal load. The technology to remotely detect seepage in bulkheaded alcoves is available. However, the high-temperature and high-radiation environments representative of postemplacement conditions in the thermally accelerated drifts will require development of applications for the technology capable of remote monitoring. Experience gained in thermally accelerated drift tests may contribute to developing technologies for such applications. Revisions to the *Performance Confirmation Plan* will update this activity description, as appropriate.

Seepage data are typically evaluated as an observed seepage occurrence (for very low flow rates) or rate at a specific location for larger flows. The number of observations of potential seepage (if seepage rate is too small to obtain a sample) compared to the predicted probability of seepage will also be evaluated. A limit on the amount of seepage and seepage composition would be established based on historical data and the sensitivity of performance assessment models. If the seepage rates, chemical composition, or probability distribution exceeded a predetermined limit, an evaluation of the potential impact of the understanding of system performance would be conducted and reported as described in Section 4.

This activity will not adversely affect the ability of the repository to meet performance objectives because the monitoring is noninvasive and occurs in the drifts remotely. The amount of seepage that could be sampled is insignificant so as to not impact water reaching the drifts. In the thermally accelerated drifts, the monitoring and testing period will be followed by closure of the test bed, which may include removing waste packages and instrumentation and sealing, as appropriate. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.3 Subsurface Water and Rock Testing

Activity Description–Laboratory analysis of chloride mass balance and isotope chemistry based on samples taken at selected locations of the underground facility. Candidate parameters that may be measured include: laboratory analysis of chloride mass balance and isotope chemistry (uranium, strontium, oxygen, hydrogen, $^{36}Cl/Cl$, ^{3}H, chlorine, ^{99}Tc and $^{129}I/^{127}I$), based on water obtained from samples taken at selected locations in the underground facility. The results represent the chemistry of water of the Upper Natural Barrier in the immediate vicinity of the repository openings, which can be used to confirm assumptions for fast paths used in unsaturated zone model. This long-term field collection activity provides a direct measurement of the parameters. Chloride mass balance data and isotopic composition data collection began in the ESF and ECRB Cross-drift during site characterization and will continue during construction, as new drifts are made available for sampling. The locations and design of the sampling and testing in emplacement drifts are very preliminary at this time. The PC Test Plans will provide additional detail and develop the logic of where and how samples would be obtained to confirm barrier capability.

Purpose–The purpose of this activity is to evaluate whether the Upper Natural Barrier operates as expected to verify assumptions for fast paths used in unsaturated zone models. Chloride mass balance and isotope geochemistry sampling and analysis are used to: (1) evaluate the amount of infiltration at the surface and the percolation flux through the repository level, (2) evaluate whether the fast pathway parameters used in the analysis adequately represent actual conditions, (3) assess the effects of water-rock interaction on the isotopic systems at the bulk rock scale, and (4) evaluate assumptions about the long-term percolation history of flow through the unsaturated zone using the ages and isotopic composition of low temperature fracture minerals.

The Upper Natural Barrier contributes to waste isolation by limiting the amount of water available to contact the Engineered Barrier System and by establishing the physical and chemical environment of the Engineered Barrier System. As shown in Figure 1-1, the Upper Natural Barrier limits flow through the volcanic tuffs in the unsaturated zone above the repository. This sampling supplements the seepage monitoring that is a direct measure of the seepage quantity and quality, but is not expected to occur over large areas of the repository. Results from this activity will be used to evaluate the chloride mass balance and isotopic signature from past events and help understand the long-term record from Yucca Mountain.

Selection Justification–This activity will obtain field observations to evaluate assumptions and inputs used in chemical models that indicate flow in the unsaturated zone. Chloride mass balance and isotopic composition can be used to understand historic infiltration rates. Information has been obtained from existing subsurface facilities, and this activity will extend the dataset to cover areas of the repository not yet sampled. While precipitation serves as the maximum input of water to the repository system from the environment, and seepage represents the output from the Upper Natural Barrier as it enters the Engineered Barrier System, rock matrix water records a long-term history of past events in the vicinity of the repository openings. As such, this activity is very important to evaluating the expected results and assumptions related to the infiltration and unsaturated zone flow in the rock above the repository models.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a moderate potential impact of the understanding of the performance of the total system. Changes in parameter values greater than that currently used as the range in the performance assessments would likely cause a reevaluation of the selected conceptual models or require consideration of additional conceptual models. Therefore, this activity will provide confirmation of the estimates of flow in the Upper Natural Barriers (BSC 2004 [DIRS 168343]).

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(1) and (2), specifically, the performance confirmation program must provide data confirming actual conditions and that indicate, where practicable, whether natural 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.

Current Understanding–Chloride mass balance data and isotopic composition data collection began during site characterization and will continue during construction. Chloride mass balance data from analysis of the ESF and the ECRB Cross-Drift samples indicate considerable spatial variability of surface infiltration and percolation flux (BSC 2004, [DIRS 169734] Section 7.1.4.4). These isotopic data will be used to evaluate the understanding of the flow and transport in the unsaturated zone.

ESF and ECRB Cross-Drift isotope geochemistry data, notably for ^{36}Cl and ^{3}H have been interpreted to indicate fast flow paths; however, the data are not mutually consistent in that fast pathways indicated by ^{3}H are not coincident with such pathways inferred from the ^{36}Cl data. The conceptual and numerical modeling insights gained from the isotope data have been used to develop a conceptual understanding of flow and transport in the unsaturated zone even though contradictions still exist in the present data sets (BSC 2004 [DIRS 168343]).

The baseline information for this activity will be synthesized from TSPA-LA results as well as from information obtained from analysis and modeling reports. Drift-scale seepage is modeled externally in the *Seepage Model for PA Including Drift Collapse* (BSC 2004 [DIRS 170000]) and the results are then abstracted as described in the *Abstraction of Drift Seepage* (BSC 2004 [DIRS 167970]), and then imported in to the TSPA-LA model before performing the performance-assessment simulations. Results of existing analyses are presented in the unsaturated zone field-testing report (BSC, 2004 [DIRS 169056]).

Anticipated Methodology–The pore-water chloride and rock and fracture coating isotope geochemistry samples will be collected at selected locations in the repository. At each locality, an approximately 2 meter long borehole will be dry drilled with "dried and filtered" compressed air. The core will be handled only with latex gloves to avoid chloride contamination, and preserved quickly to avoid undue dry out. The core will be transported to the laboratory for water extraction within 48 hours after collection. Although drilling techniques using air as the drilling fluid dry out the outer volume of the core samples, enough of the water in the core samples remains to allow for sample extraction. This is preferable to contaminating the samples with construction water. Water from the cores will be extracted by ultra centrifugation of core, and the extracted water will be analyzed by ion chromatography. Aliquots of the water will also be used to measure a comprehensive suite of dissolved ions and isotopes. The core will be used for bulk rock analyses of Uranium and Strontium isotopes. In addition to the core samples, fracture coating samples may be taken at periodic locations at selected locations in the drifts, especially at faults and at sites where a high concentration of fracture coatings suggest a high percolation flux. Fracture coating samples will also be analyzed for isotope geochemistry (e.g., uranium and strontium isotopes).

The data are typically evaluated as a set of chemical and isotopic analyses representative of the water held in the rock matrix. A limit on the composition of the matrix water as a control on seepage composition would be established based on a comparison of design criteria and the sensitivity of performance assessment models. In addition, the isotopic and chloride mass balance can be used to assess historical infiltration rates. If the potential for seepage chemical composition exceeded a predetermined limit, or isotopic composition indicates an incorrect assumption of infiltration rates, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity will not adversely affect the ability of the repository to meet performance objectives because the drilling to obtain samples is very limited and occurs in a very small portion of the drift and mains cross section. Since the amount of rock that may be sampled is an insignificant amount, impact to the pathway of water reaching the drifts is negligible, especially during the periods after closure. Before emplacement, it would be possible to seal the boreholes, as appropriate, if analytical and modeling results indicated that the small boreholes would increase seepage potential. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.4 Unsaturated Zone Testing

Activity Description–This activity includes testing of transport properties and field sorptive properties of the Topopah Spring Tuff crystal-poor member (Tptp), in an ambient seepage alcove or a drift with no waste packages emplaced. Candidate parameters that may be measured include: sorption parameters, van Genuchten parameters describing fractures and matrix, colloid or colloid-facilitated transport parameters, fracture density, apertures, coatings, air permeability, seepage, alcove temperature, and relative humidity. This activity confirms the transport properties in the immediate vicinity of the repository openings and serves as a surrogate for unsaturated welded, fractured rock of the Lower Natural Barrier below the repository. This long-term field collection and laboratory analysis activity provides direct measurements of the parameters. This activity began during site characterization and will continue during construction and emplacement.

Purpose–The purpose of this activity is to evaluate sorption coefficients used in the unsaturated zone model. The performance confirmation activities associated with the transport and sorptive properties of the Topopah Spring Tuff include testing to evaluate the assumptions and results of conceptual and numerical models used to describe flow and transport in the unsaturated zone at Yucca Mountain.

Selection Justification–Information from unsaturated zone testing will be used to support the unsaturated zone transport model. Transport of radionuclides through the unsaturated zone mainly occurs in fractures within the welded units. Because fractures are difficult to sample and test in the laboratory, in situ testing in alcoves will better assess heterogeneous effects and ultimately improve the confirmation of parameter values used in performance assessment. Transport parameters in the nonwelded units have been characterized during site characterization because of the relative ease of sampling and testing in the laboratory of units where matrix conductivity predominates. As such, there is much less uncertainty in the properties of these units so they may not need to be confirmed during performance confirmation activities. The uncertainty associated with modeling the nonwelded units is not the transport properties, but rather their spatial distribution in relation to the flow paths from the repository to the saturated zone.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a moderate potential impact on the understanding of the performance of the total system. It was estimated that there was a moderate chance that the mean annual dose calculations would change if the parameter value were found to lie outside its current modeled range. If the results of this activity are not as anticipated, the implications on the system performance could include a greater potential for radionuclide transport through the rock of the Lower Natural Barrier.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2). Specifically, the performance confirmation program must provide data that indicate, where practicable, whether natural 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.

Current Understanding–The repository horizon is underlain by approximately 215 meters to 365 meters (BSC 2003 [DIRS 165802]) of unsaturated volcanic rock. The series of unsaturated layers below the repository is comprised of tuffaceous rocks exhibiting varying degrees of welding, which affect 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.

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: (1) low water flow rates, (2) matrix diffusion that mechanically traps radionuclides in the rock, and (3) chemical adsorption of radionuclides onto mineral surfaces. Radionuclides are also dispersed spatially and temporally.

Sorption is a general term that describes a combination of chemical interactions between the dissolved radionuclides and the surrounding rock. Field transport studies will generally not address the different components of retardation: matrix diffusion, absorption, adsorption, precipitation, and ion exchange. The key factor is to identify removal of a portion of a dissolved species from the mobile liquid phase to the immobile liquid or solid phase, whatever the underlying component. This removal results in the retardation of dissolved or suspended (i.e., colloidal) transport species.

The capability of the Lower Natural Barrier is radionuclide specific. For the short-lived, radionuclides that comprise most of the repository inventory at emplacement (cesium, strontium), radioactive decay will reduce 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 will disperse and retard transport for centuries to thousands of years.

The general methodology to incorporate sorption into the transport models is to use an effective sorption coefficient. The effective sorption coefficient (K_d) represents the partitioning of a radionuclide between the solid and the aqueous phase. This coefficient, combined with the contact time, and the contact area (i.e., matrix or fracture) can be used to estimate radionuclide transport through the unsaturated zone. The baseline information for this activity will be synthesized from TSPA-LA reference database, as well as from information obtained from analysis and modeling reports. K_d values derived from field tests will be compared to the laboratory batch tests and to the K_d values presented in *Radionuclide Transport Models Under Ambient Conditions* (BSC 2003 [DIRS 163228]), the *Drift-Scale Radionuclide Transport Model* (BSC 2003 [DIRS 164889]), and the TSPA models.

Anticipated 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 of the seepage monitoring alcoves located within the repository. Testing will be initiated during the construction phase and will continue to the early stages of the emplacement phase. Because the repository is to be constructed primarily in the Topopah Spring Tuff middle nonlithophysal zone (Tptpmn) and in the Topopah Spring Tuff crystal-poor lower lithophysal zone (Tptpll), a minimum of one test will be planned and is to be conducted in the Tptpmn and one test in the Tptpll. Fracture mapping data will be used to select test locations and to ensure that the selected test locations provide good spatial coverage of the geologic units. A system of up to 9 horizontal boreholes, up to 10 meters in length, have been recommended to be drilled, stretching from the alcove floor to the ceiling.

The fracture density, apertures, and coatings will be measured and documented in both the boreholes and in the borehole core. Single and cross-hole air-injection, and water release testing will be conducted in the boreholes. 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. Samples taken from the lower boreholes will be used to document the change in tracer concentration between the upper and lower boreholes and will provide estimates of the K_d values. In addition, infiltration platforms will be constructed to conduct unsaturated flow tests and quantification the van Genuchten values that are important to modeling flow and transport in the unsaturated zone (BSC 2003, [DIRS 166509] p. 41). Continuous relative humidity and temperature measurements will be taken in and immediately outside the alcoves.

The results of the testing are compared to models that relate conservative, reactive, and colloidal tracer testing to transport properties. If the results from tracer testing exceeded a predetermined limit that would cause the assumed transport properties of the Lower Natural Barrier to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the alcoves and drilling to obtain samples is very limited and occurs in a very small portion of the repository. The amount of rock anticipated to contain residual concentrations of tracers is negligible with respect to performance. Before repository closure, boreholes and alcoves may be sealed, as appropriate, if modeling results indicated that the small boreholes and alcoves would increase seepage potential or alter the chemistry of potential water leaving the drifts. Further evaluations on waste isolation, test-to-test interference, and operations will be conducted during the detailed test planning.

3.3.1.5 Saturated Zone Monitoring

Activity Description–This activity includes monitoring, sampling, and analyzing saturated zone water from Nye County and site wells. Candidate parameters that may be measured include: water levels, electrochemical potential (Eh), hydrogen potential (pH), colloid characteristics, and radionuclide concentrations. Some very limited sampling to confirm natural colloid characteristics may be included. Water level changes indirectly control the flow components of the saturated zone feature of the Lower Natural Barrier.

Changes in gradient, as a result of local increases in water levels at the source or decreases in levels at the receptor, may reduce travel time for water. For radionuclides, water chemistry can impact transport. Eh and pH are indicators of conditions that could cause radionuclides to exhibit different transport behaviors. This long-term monitoring, field collection, and laboratory analysis activity provides direct measurements of the parameters. This activity began during site characterization and will continue during construction and the emplacement period until permanent closure.

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 of the repository. It also includes associated laboratory testing of samples to evaluate groundwater chemistry and radionuclide concentrations. These data will be used to evaluate the chemical characteristics of the groundwater, the absence of leakage from the repository unsaturated zone, and arrival of radionuclides from upgradient sources (e.g., nuclear testing).

Selection Justification–As noted above, water level changes indirectly control the flow components of the saturated zone feature. Changes in gradient as a result of local increases in water levels at the source or decreases in levels at the receptor may increase the rate of radionuclide transport. Water chemistry can impact radionuclide transport. Eh and pH are very important indicators of conditions that could cause radionuclides to exhibit different transport behaviors.

The detection of radionuclides from the repository is an indirect confirmation measurement because radionuclides from the repository are not expected to be observed at all during the monitoring. If in the highly unlikely event radionuclides from the repository were observed, this would be strong evidence that something in the repository system is not performing as anticipated. Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity evaluates assumptions that have a high potential impact on the understanding of performance of the total system. It was estimated that there was a very high chance that the mean annual dose calculations would change if the parameter value were found to lie outside its current expected range. However, there is very high confidence that the modeled range of this parameter will not be exceeded. If it were exceeded, it would cause a reevaluating of the selected conceptual models or require consideration of additional conceptual models.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2). Specifically, this activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether natural 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.

Current Understanding–The natural barrier below the repository (Lower Natural Barrier) limits and delays radionuclide movement to the accessible environment through a variety of natural processes. The saturated zone feature of the Lower Natural Barrier includes the volcanic rock and alluvium in the saturated zone below the water table that will delay the movement of most radionuclides by thousands to hundreds of thousands of years. Saturated zone processes that limit the movement of radionuclides includes: (1) low groundwater flow rates, (2) matrix diffusion, (3) sorption, and (4) filtration of colloids that could potentially transport radionuclides. Radionuclide concentrations will also be reduced by spatial dispersion of radionuclides, by mixing and dilution in groundwater.

The capability of the Lower Natural Barrier is radionuclide specific. For the short-lived, radioactive nuclides that comprise most of the repository inventory at emplacement (cesium, strontium), radioactive decay will reduce 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 to tens of 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 will disperse and retard transport for centuries to thousands of years.

The expected lack of radionuclide release and movement to the saturated zone may not be able to be evaluated directly because even a poorly performing unsaturated zone below the repository barrier is unlikely to be detected by this activity, due to the long duration of transport. Changes of surrogate indicator parameters (water levels, Eh, pH) will be closely monitored to serve as an early warning that the geohydrologic system is reacting to changes in the basin. These slight changes may not be related to activities at Yucca Mountain (in fact it may be more related to other natural or anthropogenic activities offsite upgradient on the Nevada Test Site or in Jackass Flats) but may indicate that the overall impact to the predictive models and potential long-term performance may need to be reevaluated. Information from saturated zone testing will be used to support the saturated zone transport models.

The baseline information for groundwater chemistry and water levels for this activity will be synthesized from Performance Assessment results as well as from information obtained from analysis and modeling. Modeling and analysis reports that may contain information relevant to the development of the baseline include: *Site-Scale Saturated Zone Transport* (BSC 2004 [DIRS 169053]); *Saturated Zone In Situ Testing* (BSC 2003 [DIRS 167209]); *Geochemical and Isotopic Constraints on Groundwater Flow Directions, Mixing, and Recharge at Yucca Mountain* (BSC 2004 [DIRS 169339]); *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2004 [DIRS 168473]); *Site-Scale Saturated Zone Flow Model* (BSC 2004 [DIRS 169051]); and the TSPA models.

Anticipated Methodology–This activity includes monitoring, sampling, and analyzing saturated zone water from Nye County and site wells for water levels, Eh, pH, and radionuclide concentrations. Much of the monitoring will be done with automated equipment attached to data loggers. For samples that are recovered for laboratory analysis, annual sampling or biennial sampling may be optimal. Because some of the wells may experience seasonal or shorter time variations based on storm events, some of the shallower wells (likely in the alluvium) may require quarterly sampling initially until the seasonal trends are understood.

Groundwater sampling of the Nye County and site wells for analysis of the parameters oxidation potential (Eh) and pH will be performed periodically during licensing, preemplacement construction, emplacement operations, monitoring operations, closure. Individual sampling campaigns are expected to require less than six months to complete, and can be conducted by automated equipment. Currently, field instrumentation is available for measuring water levels, Eh, and pH, and laboratory analysis is not required. However, delivery of groundwater samples to a laboratory for radionuclide concentrations analysis will be required.

The testing data are typically evaluated as water levels and chemical composition of groundwater samples. If the parameters that characterize overall chemistry lie outside of the expected range, then barrier capability may need to be reevaluated and the impact on the understanding of performance assessed. Some unexpected groundwater changes (e.g., reducing Eh or pH more conducive to precipitation of radionuclides) could positively impact performance. Emphasis will be on detecting changes that would adversely impact performance. If the results from saturated zone monitoring exceeded predetermined limits that would cause the modeled flow and transport properties of the Lower Natural Barrier to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4. The detection of radionuclides from the repository is not expected to be observed during the monitoring period. If in the highly unlikely event radionuclides from the repository are observed, this would be strong evidence that the repository barrier systems are not performing as anticipated. The NRC would be notified immediately with an analysis of system performance to follow.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the monitoring of existing wells, including the obtaining of samples, will remove only a very small amount of water from the groundwater reservoir. The amount of water that may be sampled is of such an insignificant amount as to not impact the chemical environment of the saturated zone. Before repository closure, it would be possible to seal the wells and boreholes, as appropriate, if analytical and modeling results indicated that the wells and boreholes would increase vertical migration or alter the chemistry of potential water leaving the unsaturated zone heading for the receptor. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.6 Saturated Zone Fault Hydrology Testing

Activity Description–This activity includes hydraulic and tracer testing of fault zone hydrologic characteristics, including anisotropy, in the saturated zone fractured and nonwelded tuffs to evaluate fault properties in the vicinity of Yucca Mountain. Candidate parameters that may be measured include: transmissivity, hydraulic conductivity, water flux or specific discharge, effective flow porosity, longitudinal dispersivity, sorption parameters, parameters describing diffusion between flowing and stagnant water, colloid or colloid-facilitated transport parameters; Eh, pH, and natural colloid concentrations. Results from this activity will be used to evaluate whether the flow in the saturated zone of the Lower Natural Barrier performs as anticipated. This short-duration testing, field collection, and laboratory analysis activity provides both direct and indirect measurements of the parameters. This is a new activity that will be initiated during construction. As such, the locations, durations, and design of the testing are very preliminary at this time. Testing at each potential site (which would include many separate phases of pumping, tracer injection, and recovery) is expected to be completed in one to three years.

Purpose–The purpose of this activity is to evaluate fault parameter assumptions in the saturated zone flow and transport models. The performance activities associated with the fault zone hydrologic characteristics include testing and monitoring to evaluate fault zone hydraulic conductivity (permeability), porosity, dispersivity, and anisotropy in fractured and nonwelded tuff in the flow path from the repository, are within the ranges assumed for these parameter values.

Selection Justification–Major fault zones may act as barriers to flow or as preferential pathways and both conditions have been identified near Yucca Mountain. Fault zones could affect the spreading of a contaminant plume, but might not significantly affect the unretarded radionuclide travel time. A permeable fault zone could spread flow paths vertically while retaining the general leading-edge shape of the plume.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a relatively low potential to impact total system performance because fault properties are modeled at both ends of the spectrum and have a large range. There is confidence that the modeled range of this parameter will not be exceeded, but if it were exceeded, a reevaluation of the selected conceptual models or consideration of additional conceptual models would likely be required. There is moderate confidence that the relevant time-dependent processes for the repository are captured in the parameters measured. There is moderate confidence that the relevant spatial processes for the repository would be captured in the parameters measured.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2). Specifically, this activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether natural 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.

Current Understanding–The natural barrier below the repository (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 fractured volcanic rocks from below the repository to approximately 12 to 14 kilometers south of Yucca Mountain, and the saturated alluvium at the water table from the volcanic aquifer to the accessible environment. The movement of radionuclides in the saturated zone is slow because the velocity of water that can carry them is low. In addition, several processes retard the movement of radionuclides compared to the rate of movement of the water.

Saturated zone processes that limit the movement of radionuclides includes: (1) low groundwater flow rates, (2) matrix diffusion, (3) sorption, and (4) filtration of colloids that could potentially transport radionuclides. Radionuclide concentrations will also be reduced by spatial dispersion of radionuclides, by mixing and dilution in groundwater.

The pathways for radionuclide movement immediately downgradient from Yucca Mountain occur in fractured volcanic rocks. This portion of the saturated zone barrier is complicated by the faulting and tilting of the volcanic rocks; however, it is represented in an equivalent porous medium model in terms of two weakly-coupled aquifers: (1) an upper volcanic aquifer associated with the Topopah Spring Tuff zone, and (2) a lower volcanic aquifer associated with the Prow Pass, Bullfrog, and Tram Tuff zones with some major fault zones modeled as areas of enhanced permeability. As such, hydrologic characteristics as investigated by testing are anticipated to be useful for evaluating flow paths and rates.

Variations in structure (e.g., fault zones) and permeability (e.g., high-permeability zones) in the vicinity of Yucca Mountain are known to be present. Faults may act as barriers to flow or as preferential pathways. Both conditions have been identified near Yucca Mountain. For example, if a fault causes the juxtaposition of two units with differing materials, it may act as a barrier to flow in some places and a conduit for flow at other places along its length and depth. For nonwelded units with very low matrix permeability, faults may serve as foci for numerous fractures and allow preferential flow vertically, and intercommunication between more highly permeable zones above and below the nonwelded unit. Although these types of heterogeneity are expected to result in local perturbations in the flow field, the flow regime, on a regional scale, is not expected to be significantly altered. Detailed hydrologic modeling studies of the saturated zone that have examined the effects of fault zones on flow and transport indicate inclusion of additional structure in the model would affect the spreading of a contaminant plume, but would not significantly affect the unretarded radionuclide travel time. For example, the presence of a permeable fault tends to spread flow paths vertically while retaining the general leading-edge shape of the plume.

Results of testing at the C-Well Complex indicated influences that could be attributed to fault properties. Additional detail can be found in *Saturated Zone In Situ Testing* (BSC 2003) [DIRS 167209].

Saturated zone fault hydrology testing is a new activity that will be initiated during construction. As such, the locations, durations, and design of the testing are very preliminary at this time. Based on very successful past hydraulic and tracer testing at the C-wells Testing Complex downgradient of the repository, the test sites may consist of three boreholes arranged in a triangular configuration. The *Site-Scale Saturated Zone Flow Model* (BSC 2003 [DIRS 169051]) divides the area nearest Yucca Mountain into three permeability-enhanced zones: (1) the Fortymile Wash zone, (2) the Imbricate fault zone, and (3) the Solitario Canyon fault zone. Of these three zones, the Imbricate fault zone and the Solitario Canyon fault zone are located at the eastern and western boundaries of the repository and therefore are candidates for testing.

Testing may include deepening existing wells or drilling new wells downgradient of the repository in the vicinity of a fault zone likely to be a conduit for flow (a new Southern Testing Complex). The exact location has not yet been determined. Alternative conceptual models may need to be evaluated before the appropriate locations are selected. Another new test site may be located in the Solitario Canyon fault zone. The exact location has not been determined, but three new boreholes would be drilled in, and across, the Solitario Canyon fault, and packers installed to allow three-dimensional hydraulic and tracer testing. As in the Southern Testing Complex, the testing may probably 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.

Because this is a new activity, an established baseline is not available at this time. Whereas testing activities very similar to this have been conducted during site characterization at the C-wells Testing Complex and in the interpretation of boundary conditions noted in other hydraulic single well tests, this specific performance confirmation activity will not begin until construction begins. Therefore, the baseline information for this activity will be synthesized from performance assessment assumptions as well as from published results from analogue sites in fractured and faulted rocks.

Anticipated 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. Testing may include single and cross-hole pumping and tracer tests using boreholes with spacing (both in plan view as well as with depth) depending on predictive modeling and test objectives. Fault testing will likely be conducted at two test locations in the repository area. The boreholes could both straddle and penetrate the test faults. Downhole packers would be used to isolate several test intervals in each borehole allowing each borehole to function as point sources. The use of three boreholes and in situ packers allows cross-hole hydraulic and tracer testing in both the horizontal and vertical planes. The packers would also allow boreholes that penetrate the fault to be used to conduct tests in the hanging wall, fault zone, and the footwall. Single-hole and cross-hole hydraulic testing could be used to quantify the fault zone hydraulic conductivity, porosity, and anisotropy. Cross-hole tracer testing could be used to evaluate dispersivity and sorption characteristics.

The testing data are typically evaluated as results of hydraulic and tracer testing. These results are compared to models that relate hydraulic properties to flow and conservative, reactive and colloidal tracer testing to transport properties. If the results from hydraulic and tracer testing exceed a predetermined limit that would cause the assumed flow and transport properties of the saturated zone feature of the Lower Natural Barrier to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the new wells that may be tested, including obtaining samples, remove only a very small amount of water from the fractured and nonwelded tuffs of the groundwater reservoir. The amount of water that may be sampled is of such an insignificant amount as to not impact the chemical environment of the saturated zone. The amount of rock that could contain residual concentrations of tracers is of such an insignificant amount as to not impact the chemical environment of groundwater in the flow path, especially during the periods after closure when the saturated zone would be considered an active participant in barrier performance. Before repository closure, it would be possible to seal the wells and boreholes, as appropriate, if analytical and modeling results indicated that the wells and boreholes would increase the probability of vertical migration or alter the chemistry of potential water traveling through the rock heading for the receptor. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.7 Saturated Zone Alluvium Testing

Activity Description–This activity includes use of the Alluvial Test Complex tracer test using multiple boreholes to evaluate transport properties of the alluvium along a potential flow path south of Yucca Mountain. Candidate parameters that may be measured include: transmissivity, hydraulic conductivity, water flux and specific discharge, effective flow porosity, longitudinal dispersivity, sorption parameters, parameters describing diffusion between flowing and stagnant water; colloid or colloid-facilitated transport parameters; Eh, pH, and natural colloid concentrations. Results of this activity will be used to evaluate if the saturated zone alluvium feature of the Lower Natural Barrier performs as anticipated. This short-duration testing, field collection, and laboratory analysis activity provides both direct and indirect measurements of the parameters. This activity began during site characterization but was suspended when a permit to withdraw water and inject was denied by the State of Nevada. The testing is expected to begin again, and continue during the early stages of construction. Completion of the testing is anticipated to take from one to three years.

Purpose–The purpose of this activity is to evaluate inputs and assumptions for the saturated zone flow and transport models. The performance activities associated with the Alluvial Test Complex include testing and monitoring of the alluvium to evaluate the assumptions and results of conceptual and numerical models used to describe the saturated zone hydrologic conditions in the alluvium south of Yucca Mountain. Cross-hole pump and tracer transport tests will be conducted.

Selection Justification–Alluvium properties could influence evaluation of the performance of the Lower Natural Barrier. If, in the unlikely event that the transport parameters for alluvium are outside of the expected range in the adverse direction, then the ability of the alluvial feature of the Lower Natural Barrier to meet the objectives of the barrier capability would be evaluated. The assumed range from analogue studies is very broad and has a mean value representing less retardation potential than many other investigators would choose. Because of early results from single well tracer tests at the Alluvial Testing Complex that indicated that there was little to no matrix diffusion the performance assessment models take little credit for retardation due to matrix diffusion in the alluvium. Further, the transport model takes into account uncertainty in the alluvium transport properties as well as uncertainty about where, along the flow paths from Yucca Mountain, water potentially carrying radionuclides would actually enter the alluvial materials from the fractured tuffs.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a relatively high potential impact on the performance of the total system. It was estimated that there was a very high chance that the mean annual dose calculations would change if the parameter value were found to lie outside its current modeled range. There is very high confidence that the modeled range of this parameter will not be exceeded but if it did, it would cause a reevaluation of the selected conceptual models or require consideration of additional conceptual models.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2). Specifically, this activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether natural 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.

Current Understanding–The natural barrier below the repository (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 fractured volcanic rocks from below the repository to approximately 12 to 14 kilometers south of Yucca Mountain, and the saturated alluvium at the water table from the volcanic aquifer to the accessible environment. The movement of radionuclides in the saturated zone is slow because the velocity of water that can carry them is low. In addition, several processes retard the movement of radionuclides compared to the rate of movement of the water.

Saturated zone processes that limit the movement of radionuclides includes: (1) low groundwater flow rates, (2) matrix diffusion, (3) sorption, and (4) filtration of colloids that could potentially transport radionuclides. Radionuclide concentrations will also be reduced by spatial dispersion of radionuclides, by mixing and dilution in groundwater.

Sorption is a general term that describes a combination of chemical interactions between the dissolved radionuclides and the surrounding rock. Field transport studies will generally not address the different components of sorption: absorption, adsorption, precipitation, and ion exchange. The key factor is to identify removal of a portion of a dissolved species from the mobile liquid phase to the immobile solid phase, whatever the underlying component. This removal results in the retardation of dissolved or suspended (i.e., colloidal) transport species.

Because the alluvial materials are a porous media with few connected fracture pathways, water flow and radionuclide transport occur in intergranular pores. The conceptual model for transport in the alluvial sediments is that of a porous continuum. The effective porosity of the alluvium is greater than the fracture porosity of the tuffs. Consequently, pore velocities in the alluvium are smaller than those in the fractures of the volcanic aquifers. Sorption onto minerals in the alluvium results in retardation of the radionuclide movement relative to the water movement in these sediments.

Testing and quantification of the hydraulic and transport characteristics of the alluvium was deemed necessary in order to meet the requirements of 10 CFR Part 63. The Alluvial Testing Complex is located approximately 18 kilometers south of Yucca Mountain along a potential groundwater flow path parallel to Fortymile Wash. The test complex consists of three Nye County Early Warning Detection Program boreholes (NC-EWDP-19D1, I9IM1, and 19IM2) along with a single piezometer borehole (NC-EWDP-19P). The boreholes are arranged in a quasi-triangular configuration. The distance between the boreholes ranges from approximately 10 to 30 meters. To date, single-hole hydraulic and tracer testing has been conducted at the Alluvial Testing Complex in borehole NC-EWDP-19D1. This work and the analysis are documented in *Saturated Zone In Situ Testing* (BSC 2003 [DIRS 167209]). The Alluvial Testing Complex data was used to develop estimates of groundwater specific discharge. The Alluvial Testing Complex data reduces the uncertainty in the specific discharge estimates originally developed based on input from an expert elicitation panel and the results from hydraulic and tracer testing in tuff. The uncertainties in the specific discharge estimates are incorporated into the flow and transport models using a cumulative distribution function.

The baseline information for groundwater chemistry and water levels in the alluvium for this activity will be synthesized from TSPA-LA results as well as from information obtained from analysis and modeling reports. Reports that may contain information relevant to the development of the baseline include: *Site-Scale Saturated Zone Transport* (BSC 2004 [DIRS 169053]); *Saturated Zone In Situ Testing* (BSC 2003 [DIRS 167209]); *Geochemical and Isotopic Constraints on Groundwater Flow Directions, Mixing, and Recharge at Yucca Mountain* (BSC 2004 [DIRS 169339]); *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2004 [DIRS 168473]); *Site-Scale Saturated Zone Flow Model* (BSC 2004 [DIRS 169051]); and the TSPA models.

Anticipated 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. Three boreholes will be used to conduct single hole and cross-hole hydraulic and tracer tests at locations representative of the saturated thickness of the alluvium. Tracer tests include conservative tracers, nonconservative tracers, and polystyrene microspheres. Pressures, temperatures, and flow rates will be recorded during testing. Packers will be used to isolate the screened intervals in the boreholes. Flow rates will be recorded using calibrated flow meters. During hydraulic testing, a borehole will be pumped while other boreholes serve as observation wells. Prior to conducting tracer tests, selected intervals will be pumped to quantify vertical leakage in the well. The results of this test will determine the analysis methods necessary to conduct hydraulic tests and to determine which intervals will be used for the cross-hole tracer tests.

Injection pump back tests will also be conducted. Tracer tests using fluorinated benzoic acid and bromide will be followed by tests using fluorescent polystyrene microspheres and natural colloids that have ^{152}Sm sorbed onto them. The microsphere and ^{152}Sm responses will provide estimates of colloid transport parameters and the colloid facilitated radionuclide transport parameters. The results from the benzoic acid and bromide tracers will provide estimates of longitudinal dispersivity and diffusive mass. Lithium will be used as a reactive tracer in cross-hole tracer testing. Comparison of its field transport behavior with its laboratory transport behavior is important in evaluating the TSPA use of laboratory derived sorption parameters in field scale radionuclide transport predictions. Additional laboratory batch and column sorption tests will be conducted to compare the sorption values of lithium and other tracers with the sorption values of radionuclides such as ^{237}Np. These laboratory tests will be used to confirm the basis for modeling saturated zone flow and transport or for modeling sorption in the alluvium.

The testing data are typically evaluated as results of tracer testing. These results are compared to models that relate conservative, reactive and colloidal tracer testing to transport properties of the alluvium as part of the saturated zone feature of the Lower Natural Barrier. If the results from tracer testing exceeded a predetermined limit that would cause the assumed transport properties of the Lower Natural Barrier to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the existing wells that will be tested, including obtaining samples, remove only a very small amount of water from the alluvial deposits of groundwater reservoir. The amount of water that may be sampled is of such an insignificant amount as to not impact the chemical environment of the saturated zone. The amount of alluvium that will contain residual concentrations of tracers is of such an insignificant amount as to not impact the chemical environment of groundwater in the flow path, especially during the periods after closure when the alluvium would be considered an active participant in barrier performance. Before repository closure, it would be possible to seal the wells and boreholes, as appropriate, if analytical and modeling results indicated that the wells and boreholes would increase the probability of vertical migration or alter the chemistry of potential water traveling through the alluvium heading for the receptor. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.8 Drift Inspection

Activity Description–This activity includes regular inspection of nonemplacement drifts, and periodic inspection of emplacement drifts, thermally accelerated drifts, and other underground openings using remote measurement techniques, as appropriate. Candidate parameters that may be measured include: temperature (as a surrogate indicator of evaporating seepage), seepage, rockfall, size and frequency monitoring, ground support conditions, engineered barrier component positions, drift continuity. This inspection aids in ensuring that designed systems are operating as expected. This activity evaluates the potential environment that components of the Engineered Barrier System will endure and that the option for retrievability is preserved. This long-term field observation and measurement activity provides direct measurements. This is a new activity that focuses on areas important to repository operations and confirming preservation of the option to retrieve spent nuclear fuel and high-level radioactive waste, although similar inspection activities were conducted in the ESF, alcoves and ECRB Cross-Drift. Periodic drift inspections will begin during operations and will continue through closure. Planning for this activity is preliminary in nature; frequency of observations, other methods and approaches may be employed and will be described in the PC Test Plans prior to construction.

Purpose–The purpose of this activity is to evaluate drift stability assumptions, both within emplacement drifts and nonemplacement drifts, and rockfall size or probability distributions. The activity also supports confirmation of retrievability. Inspection includes detection or measurement of significant rockfall, drift convergence, changes in waste package position, and changes to rail alignment. Inspection to evaluate performance and design assumptions includes detection of temperature, liquid seepage, and degradation not directly related to retrievability.

Selection Justification–Mechanical effects from rockfall associated with drift degradation over time may lead to failure of the drip shields and waste packages. The failure of the Engineered Barrier System will depend on the rate of accumulation of rubble and rate of rockfall in the drift and the threshold load-bearing capacity of the systems. The accumulation in the drift will increase the waste package temperatures and may affect the water seepage into the drifts. As such, this observation activity is important to the drift stability modeling and has impacts on seepage and thermal processes within the drifts.

If the observations indicate a change in the parameter value greater than that currently expected, that result would likely change the selected conceptual models or require consideration of additional conceptual models. As such, if the results of this activity are not as anticipated, the implications on system performance could have impacts on the environment to which Engineered Barrier System components will be subjected in the repository and the ability to retrieve spent nuclear fuel and high-level radioactive waste if needed. Mechanical loading from rockfall rubble accumulated from drift degradation over time may lead to failure of the drip shields and waste packages. For the reasons presented above, this activity is designed to meet the requirement to confirm that the design preserves the option to retrieve waste. It also addresses the requirement for the collection of data for geotechnical and design parameter confirmation by monitoring the drift environment (temperature and humidity), seepage, and waste package corrosion. Specifically, this activity addresses the requirements of 10 CFR 63.111(e), 10 CFR 63.131(a)(1), and 10 CFR 63.132(a), (b), and (e).

Explicitly, 10 CFR 63.111(e) requires that the geologic repository operations area is to be designed to preserve the option of waste retrieval. Confirmation of the retrieval option must continue during the operations period until completion of a performance confirmation program and the NRC review of the information obtained.

This activity also addresses the requirement that the performance confirmation program provide data that indicate, where practicable, whether 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 that the 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. Furthermore, that during repository construction and operation, a continuing program of surveillance be conducted to ensure that geotechnical and design parameters are confirmed, that subsurface conditions must be monitored and evaluated against design assumptions, and that in situ monitoring of the thermal-mechanical response of the underground facility be conducted until permanent closure, to ensure that the performance of the geologic and engineering features is within design limits.

Current Understanding–This long-term field observation and measurement activity includes inspection of selected emplacement drifts to confirm that the design preserves the option to retrieve spent nuclear fuel and high-level radioactive waste after placement of the waste packages. The length of the emplacement drift will be subject to inspection, but monitoring may not include the entire length of the drift during each inspection. Inspections will be conducted remotely with cameras or other equipment. In addition, sensor devices to measure temperature, other environmental conditions, and make observations of potential drift seepage would be included on a gantry or other remote monitoring mechanism.

Inspections will involve monitoring drift stability (deterioration of the crown or ribs), and any resulting degradation of the rail and other systems. Preservation of the retrievability option within the emplacement drifts requires continued functionality of the drift opening and rail system. Failure of these elements could impact retrieval of waste. Additionally, the performance confirmation monitoring itself must not adversely impact waste retrieval.

Rail system obstruction, misalignment, or damage to the extent it inhibits a waste package gantry from traveling along the track could be caused by unlikely occurrences of drift invert heave or drift rockfall. 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.

Regularly scheduled monitoring of selected emplacement drifts will be performed. However, following significant seismic events, monitoring emphasis will be directed, as appropriate, at areas with significant geologic features identified during emplacement drift mapping to evaluate movement or damage to engineered systems.

During operational activities, the waste package could be misaligned (impacting retrievability) by placement gantry malfunction. The position of the package during initial placement in the drift would be monitored and corrected by the operations department and is not considered a part of retrievability monitoring under the performance confirmation program. Also, emplacement door functionality is not included in the scope of the performance confirmation program, since this is considered to be an operations function and not a barrier assumed after permanent closure. The operations department would monitor design systems outside including the emplacement access doors for retrievability. This is in agreement with the current philosophy that is discussed in the *Emplacement and Retrieval System Description Document* (BSC 2004 [DIRS 167280]).

The design confirmation data preserve the option for spent nuclear fuel and high-level radioactive waste retrieval and would include video (visual documentation of drift condition) or convergence measurement data gathered with remote monitoring equipment. Convergence monitoring data, on the other hand, would be collected and analyzed. The data are typically evaluated as a convergence rate. A limit on the rate of convergence would be established based on historical data and performance assessment models.

The baseline for this activity will be developed from reports that may include: *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (BSC 2003 [DIRS 166183]); *Supporting Rock Fall Calculation for Drift Degradation: Quantification of Uncertainties* (BSC 2001 [DIRS 158207]); *Drift Degradation Analysis* (BSC 2004 [DIRS 168550]); *Evaluation of Emplacement Drift Stability for KTI Resolutions* (BSC 2004 [DIRS 168889]); and *Supporting Rock Fall Calculation for Drift Degradation: Drift Reorientation with No Backfill* (CRWMS M&O 2000 [DIRS 149639]). This comparison will indicate whether the ranges for the parameters measured in situ are consistent with the data used as the basis for the conceptual models and the ranges used for the input parameters for the numerical models relevant to drift stability.

Anticipated Methodology–Although the concepts for this activity have not yet been planned, and would not be finalized until needed during waste emplacement, it is likely that the technology will consist of using a remotely operated vehicle equipped with cameras and sensing devices. The cameras may be designed to provide stereographic views and projections of the drift wall and invert. Sensors would provide measurements of temperature and seepage within the drifts. General observation of seepage (Section 3.3.1.2) (if any) will also be conducted in conjunction with drift inspections. This activity may benefit from the past experiences in acquiring remote visual observations in the ESF Drift Scale Test using the camera. 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 meter long drift on a gantry and provided video, still, and infrared images of the drift. These images were used to assess drift stability conditions, look for evidence of seepage, and to observe the general conditions of the simulated waste packages and test components.

Planning for this activity is preliminary in nature; other methods and approaches may be employed and will be described in the PC Test Plans prior to construction. This activity will not adversely affect the ability of the repository to meet performance objectives because the monitoring is noninvasive and occurs in the drifts remotely. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.9 Thermally Accelerated Drift Near-Field Monitoring

Activity Description–This activity includes monitoring of near-field coupled processes (thermal-hydrologic-mechanical-chemical) properties and parameters associated with the thermally accelerated drifts. Candidate parameters that may be measured include: rock-mass moisture content, temperatures, air permeability (fracture permeability), mechanical deformation, mechanical properties, and water chemistry. This activity monitors the near-field properties in the immediate vicinity of the thermally accelerated drifts and serves as a surrogate for anticipated conditions during the thermal pulse and changes that may result after the thermal pulse in the fractured unsaturated rock above and below the repository of the Upper and Lower Natural Barriers. This long-term remote field monitoring and testing provides both direct measurements and indirect observations.

This is a new activity that will be conducted within the thermally accelerated drift and will be initiated during operations, continuing until closure. As such, for the field-testing, the locations, durations, and design of the testing are very preliminary at this time. This monitoring will be conducted periodically at a frequency yet to be determined. Other methods and approaches may be employed and will be described in the PC Test Plan prior to waste operations.

Purpose–The purpose of this activity is to evaluate coupled process results from the thermal-hydrologic-chemical-mechanical models. This activity monitors the near-field properties in the immediate vicinity of the thermally accelerated drift walls and serves as a surrogate for anticipated conditions during the thermal pulse and resulting permanent changes that may result after the thermal pulse in the fractured unsaturated rock above and below the repository subsides. Ongoing evaluation of these coupled processes that affect water chemistry, porosity and matrix and fracture permeability is intended to assess the predicted repository performance bases pertaining to drift seepage.

Selection Justification–Monitoring of thermal-hydrologic-mechanical-chemical coupled processes are important to the evaluation of the near-field coupled processes surrounding the repository emplacement drifts. Seepage into waste emplacement drifts could be a significant factor in waste isolation because of its potential to contribute to degradation of engineered barriers and radionuclide transport. Boiling of pore water will generate water vapor, which will flow along paths of least resistance, followed by transport to and condensation in cooler rock surrounding the emplacement drifts. Water chemistry evolves as a result of the thermal-hydrologic-chemical processes that occur within this elevated temperature zone. In addition, thermal-hydrologic-mechanical effects give rise to thermally-induced fracture aperture changes that lead to changes in fracture permeability. Further, redistribution of moisture from thermal-hydrologic processes is also reflected in time evolution of fracture permeability.

Changes in the near-field environment during the thermal pulse could change seepage patterns and compositions as well as drift stability. Section 3.3.2.4 complements this activity. This long-term field collection and laboratory analysis activity provides relatively direct measurements as well as indirect observations expected to evolve during the preclosure period due to both natural evolution and repository activities and will likely vary spatially.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, changing seepage enhancing conditions due to drift degradation or focusing of flow because of residuals from thermal processes (e.g., plugging of fractures or enhanced flow through fractures activated by thermal-mechanical processes) were judged to be significant. There is confidence that the modeled range of the rock-mass moisture content, fracture permeability, and perturbed thermal effects will not be exceeded. A change in these rock water parameter values, greater than that currently used as the range in the performance assessments, would change the selected conceptual models or require consideration of additional conceptual models.

For the above reasons, this activity is important. In addition, the near-field environment is important to evaluating the performance life times of the Engineered Barrier System components, as well as the drift stability after heating and cooling. For the reasons presented above, this activity is designed to meet the requirements of 10 CFR 63.131(a)(1) and (2), 10 CFR 63.132(a), (b), (c), and (e); and 10 CFR 63.133(a). Specifically, that the performance confirmation program provide data that indicate, where practicable, whether the 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 that the natural and engineered systems and components are functioning as intended and anticipated.

In addition, a continuing program of surveillance, measurement, and testing must be conducted to ensure that geotechnical and design parameters (e.g., near-field environment) are evaluated. Subsurface conditions must be monitored and evaluated against design assumptions. 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.

During the early or developmental stages of construction, a program for testing of the thermal interaction effects of the Engineered Barrier System features, rock, unsaturated zone, and saturated zone water, must be conducted. This activity provides the data for the unsaturated zone rock and water portion of the requirements for 10 CFR 63.133(a). Because of the distance to the saturated zone and the slow migration of the thermal pulse during the performance confirmation period, it is not prudent to test for coupled process behavior in the saturated zone. Model results indicate negligible effects on saturated zone water levels and chemistry based on thermal conditions anticipated from the repository.

Current Understanding–Estimating the evolution of the near-field environment is complex because of coupled thermal-hydrologic-mechanical-chemical processes and changes in the emplacement drift configuration caused by the collapse and rubbling of overlying rocks. 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, corrosion products, or both. Major processes affecting the evolution of the near-field environment include evaporative processes and mineral dissolution and precipitation, as well as aqueous and gaseous-phase transport and chemical reactions.

The near-field environment is defined as the conditions within the repository region, including the rock immediately surrounding the drifts outward to a distance that encompasses significant heating related processes or excavation related changes in rock properties (DOE 2002, [DIRS 155943] p. G-20). "Significant" refers to the effect on the repository system performance.

Interactions between the natural system and radioactive wastes could cause both permanent and transient property changes within a region that extends for a considerable distance into the rock mass (BSC 2004 [DIRS 170338]; BSC 2003 [DIRS 164890]; BSC 2003 [DIRS 162050]; BSC 2003 [DIRS 166498]). Beyond this near-field lies the far-field (i.e., relatively unaltered host rock of the unsaturated zone and saturated zone), where only minor changes may occur, such as slightly elevated temperatures. The near-field may extend considerably farther for some processes than for others (BSC 2003, [DIRS 162050] Figure 6.8-40; BSC 2003, [DIRS 164890] Figure 7.4.3-2), ranging from tens of meters to 100 meters or more outward from the emplacement drift (BSC 2003, [DIRS 162050] Section 6; BSC 2003, [DIRS 164890] Figure 7.4.3; BSC 2003, [DIRS 166498] Sections 6.2 and 6.3). The near-field also evolves as the rate of heat generation from the decay of the radioactive waste decreases over time.

Three field thermal tests have been conducted to obtain a more in depth understanding of the thermal-hydrologic-mechanical-chemical coupled processes and to provide data for enhancing confidence in the model analyses. Those tests are the Drift Scale Test, Large Block Test, and the Single Heater Test. The tests were conducted in the Tptpmn; the Single Heater Test and the Drift Scale Test were conducted in situ (at Alcove 5 of the ESF) and the Large Block Test was conducted in a nearby outcrop located at Fran Ridge. Detailed descriptions of the Drift Scale Test, the Large Block Test, and the Single Heater Test can be found in the following reports: *Drift Scale Test Design and Forecast Results* (CRWMS M&O 1997 [DIRS 146917]), *Drift Scale Test As-Built Report* (CRWMS M&O 1998 [DIRS 111115]), *Large Block Test Final Report* (Lin, et. al. 2001 [DIRS 159069]), and the *Single Heater Test Final Report* (CRWMS M&O 1999 [DIRS 129261]). Results from characterizing the Drift Scale Test block are contained in the *Ambient Characterization of the Drift Scale Test Block* (CRWMS M&O 1997 [DIRS 101539]). Early results of the Drift Scale Test are discussed in the *Drift Scale Test Progress Report No. 1* (CRWMS M&O 1998 [DIRS 108306]) and *Thermal Testing Measurements Report* (BSC 2002 [DIRS 160771]). Thermal testing measurements for all three tests are reported in *Thermal Testing Measurements Report* (BSC 2002 [DIRS 160771]). Performance assessment process models that use these measurements are described in the following reports: *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 163056]); *Drift-Scale Coupled Processed (DST and THC Seepage) Models* (BSC 2004 [DIRS 168848]); *Drift Scale THM Model* (BSC 2004 [DIRS 167973]); and the *Abstraction of Drift-Scale Coupled Processes* (BSC 2004 [DIRS 169617]).

An established baseline is not available at this time, especially as it relates to conditions created by actual waste packages or to conditions in units other than the Tptpmn. Very successful past thermally induced property monitoring activities, very similar to this, have been conducted during site characterization in the ESF and ECRB Cross-Drift (although not remotely) and are currently ongoing (the references are cited in the previous paragraphs). This specific performance confirmation activity will not begin until the thermally accelerated drift test bed is constructed and waste packages emplaced.

Near-field monitoring will collect data that will be compared with ranges of acceptability established in current numerical models and thermal results reports: *Drift Scale THM Model* (BSC 2003 [DIRS 164890]), *Drift Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2002 [DIRS 158375]), and *Thermal Hydrological-Chemical (THC) and Thermal Hydrological (TH) Only Drift Scale Model Analysis* (DTN: SN0002T0872799.007 [DIRS 148605]), *Abstraction of Drift Scale Coupled Processes* (BSC 2004 [DIRS 169617]), *Multiscale Thermohdrologic Model* (BSC 2004 [DIRS 163056]), and *Thermal Measurements Report* (BSC 2002 [DIRS 160771]). These comparisons will indicate whether the ranges for the parameters measured in situ are consistent with the data used as the basis for the conceptual models and the ranges used for the input parameters for the numerical models relevant to seepage and coupled processes.

Anticipated Methodology-General–This long-term remote field monitoring and testing activity includes monitoring that will be accomplished using boreholes drilled into the near-field rock surrounding the thermally accelerated emplacement drifts. These boreholes will be collared in the test observation drift or subsidiary alcoves located beneath the emplacement drift and dry drilled toward, but not intersecting, a thermally accelerated emplacement drift. Arrays of boreholes will be designed, depending on the type of monitoring to be performed. Each array will define the number of boreholes, the location, and the orientation for specific monitoring measurements to be performed. During drilling operations, core will be collected from each hole to evaluate initial in situ rock moisture content and chemistry. The following monitoring methods may be used for data collection in the near-field surrounding a thermally accelerated emplacement drift.

Anticipated Methodology–In-Hole Logging–Regular ongoing measurement of water saturation will likely be performed using neutron and induction in-hole logging techniques. This will provide actual moisture content in the rock immediately surrounding each borehole.

Induction logging is a subsurface geophysical technique that measures formation conductivity as a function of temperature and moisture. Accuracy for this measurement diminishes in highly resistive environments. Because of this, induction logging will only be used as a secondary means in place of neutron logs to measure actual moisture content.

Anticipated Methodology–Tomographic Analysis–Additional borehole arrays for broader spatial measurement of relative changes in water saturation will include electrical resistivity tomography and ground penetrating radar. Electrical resistance tomography testing is a geophysical technique involving paired source (i.e., current) and receiver (i.e., voltage) electrodes, located along the length of specifically oriented boreholes, preferentially selected to either send or receive electrical signals. The measurements of voltage and current are used to map the moisture content in the rock between boreholes. The system is capable of monitoring the change in water saturation levels as the boiling front moves through the rock mass.

Ground penetrating radar is a geophysical technique that requires calibration of the measured dielectric coefficient to moisture content and temperature. Ground penetrating radar measurement could potentially be conducted in the boreholes used for neutron logging. This technique applies radar in a cross-hole and topographic fashion in the heated rock to derive temporal changes in the dielectric properties of the rock mass. These data are then used to infer temporal and spatial saturation changes as heating progresses.

Anticipated Methodology–Permeability–Air permeability testing will be used for monitoring the fracture permeability changes in the rock resulting from moisture redistribution and fracture closure or opening from thermally induced stresses. Permeability tests will be performed in selected zones surrounding a thermally accelerated drift where modeling results indicate that thermal-hydrologic-mechanical-chemical processes may result in permeability changes. Fracture permeability measurements involve injecting a gas into a test zone within a borehole and measuring the pressure response. The tests will generally be conducted in boreholes that lie above and below the thermally accelerated heated emplacement drift.

Anticipated Methodology–Chemical Analysis–The boreholes used for permeability testing may also be used for obtaining water samples for chemical analysis in addition to water samples from core. Water samples will be collected and isotopic and ionic analyses will be performed to assess the source of the seepage water (e.g., percolation or condensation).

Anticipated Methodology–Rock Displacement and Stress Measurements–Mechanical measurements will also include the measurement of stress and displacement in the rock surrounding a thermally accelerated emplacement drift. The boreholes used for these measurements will be generally oriented perpendicular to the axis of the emplacement drift or in an orientation necessary to measure the maximum in situ stress.

Measurements for rock displacement will most likely be accomplished using multi-point borehole extensometers (MPBXs), acoustic emissions, or tiltmeters. Displacement data from MPBXs can be used to determine the location, rate of movement, and a calculated strain. Additionally, the development of the three-dimensional deformation field in the heated rock mass may be monitored by using an array of high-resolution tiltmeters. The tilt data will be used to map the rock mass displacement field over time. Displacements, combined with temperature data, will provide a measure of the rock mass thermal expansion coefficient.

Measurements of in situ stress, and the changes to that stress field, can address the following situations:

- Confirmation of the expected reversal in directions of the principal stresses. Currently the maximum compressive in situ stress is the vertical (i.e., overburden) stress. The thermal loading from the emplacement of waste is expected to increase the horizontal compressive stresses such that they become the maximum principal stress.
- Identification of stress failures.
- Detection of mechanical events (e.g., fracture formation, fracture slippage, rock failure in drifts) that might be indicated by sudden and discontinuous changes in stress.

There are basically two objectives for performance confirmation testing and data gathering for rock displacement and stress measurement: (1) to evaluate the predicted conditions of the underground rock during repository performance; and (2) to detect conditions that significantly differ from those predicted, especially if the new conditions might indicate scenarios that would impact successful repository performance. The first item regarding the shift of the principal stresses satisfies the first objective for performance confirmation. The second and third items address the second objective, but require some definition of a negative-impact scenario. For example, preliminary failure stress curves have been developed from the recent series of pressurized slot tests in the ESF and ECRB Cross-Drift; these curves indicate combinations of normal and shear stress values at which shear failure begins in the lithophysal rock. Measurements of stresses would identify locations where stresses were approaching such a failure curve. Similarly, sudden changes in stress might indicate large-scale rock fracturing and possible rockfall conditions in an emplacement drift. Such rockfall events are expected to occur during the course of the repository's life. Stress measurement data can be used to evaluate preemplacement predictions of this behavior, as well as indicate if rockfall conditions are significantly different, better, or worse than the predicted performance.

Anticipated Methodology-Thermal-Hydrologic–Commercially available resistive temperature devices or other types of temperature sensors will be used to measure the temperature in the surrounding near-field rock for thermally accelerated drifts. Resistive temperature devices will likely be installed in an array of boreholes drilled to form vertically oriented planes that are orthogonal to the longitudinal axis of the emplacement drift. This configuration of thermal sensors is useful in comparing field measurements with model predictions and in characterizing the rocks natural thermal property heterogeneity. Monitoring temperatures within these planes also provides information on the evolution of the temperature field with time, including signatures of phase change.

The testing data for the overall activity are typically evaluated as results of in situ rock properties and recovered samples of water as they change in response to the thermal pulse. These results are compared to models that relate thermal-hydrologic-mechanical-chemical behavior of the rock of the Upper and Lower Natural Barriers. If the results from testing and monitoring exceeded a limit that would cause the modeled rock properties of the Upper and Lower Natural Barrier in the near-field to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the instrumentation is superficial to the drift wall and the remote techniques will not affect the waste packages or in-drift conditions. If drilling is used to emplace instrumentation, it will be very limited and occur in a very small portion of the drift. The amount of rock that may be disturbed is of such insignificant amount as to not impact the pathway of water reaching the drifts, especially during the periods after closure. However, before closure, it may be possible to remotely seal the boreholes, as appropriate, if analytical and modeling results indicated that the small boreholes would increase seepage potential. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.10 Dust Buildup Monitoring

Activity Description–This activity includes monitoring and laboratory testing of quantity and composition of dust on engineered surfaces. Candidate parameters that may be measured include: quantity, physical properties, and chemical composition of dust deposited on waste packages, drip shields, rail, and ground support surfaces. Results from this activity will be used to assess the potential environment that components of the Engineered Barrier System will endure. Dust monitoring activities in the ESF similar to this performance confirmation activity, have been conducted during site characterization and are currently ongoing. This specific performance confirmation activity will begin during construction and operation. This long-term field collection provides a direct measurement and indirect observations of the parameters. Dust will be collected in representative locations to be specified in the PC Test Plans for this activity. This activity will be done in representative emplacement drifts and individual locations selected based on ventilation variations. The sample locations will be representative and selected after startup of the ventilation system. Sampling will also be conducted in the thermally accelerated drift test bed to complete the data set for those activities. The locations will be sampled periodically on a frequency yet to be determined. Other methods and approaches may be employed and will be described in the PC Test Plans prior to waste operations.

Purpose–The purpose of this activity is to evaluate assumptions of dust buildup and potential chemical effects. Results from this activity will be used to assess a part of the potential environment that components of the Engineered Barrier System will endure. The accumulation of dust on the surface of the drip shield (once installed) and on the waste package outer barrier has a role in determining the chemical characteristics of the aqueous environment in which these two Engineered Barrier System metallic components will operate in the repository. "Dust" is a collective term that is meant to include a variety of particulate material that originates from various sources.

Selection Justification–Dust buildup contributes to corrosion of the waste package, drip shield, and other engineered components, because of possible impacts on water chemistry and deliquescence. Because dust contributes in determining the chemical characteristics of the environment in which Engineered Barrier System components will operate in the repository, this activity is important to evaluating the bases for the expected conditions and to assess if the environments being used in the waste package and waste form testing are representative. Salts that are present as aerosols in atmospheric air and entrained in ventilation air introduced into the repository drift may be deposited on the drip shield and waste package surfaces. Evaluating the range in chemistry of water contacting the engineered barriers is important for determining corrosion rates of the engineered materials.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a potential impact on the understanding of the performance of the total system. Mean annual dose calculations that consider the effects of localized corrosion may change if monitored parameter values were found outside the range used in the model. There is moderate confidence that the modeled range of this parameter will not be exceeded during the compliance period, thereby increasing its need for evaluation. In addition, if the range were exceeded, a change in the parameter value greater than that currently used as the range in the performance assessments, would likely change the selected conceptual models or require consideration of additional conceptual models. As such, if the results of this activity are not as anticipated, the implications on system performance could include a greater potential in the waste package corrosion failure mode and accordingly, a greater potential for Engineered Barrier System breach and radionuclide release to the Lower Natural Barrier.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2) and 10 CFR 63.134(a)(c). Specifically, the activity addresses the requirement that the 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 by providing insight into the environment in which they will endure. It is required that a program be established at the geologic repository operations area for monitoring the condition of the waste packages and that 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. This activity evaluates portions of that representative environment.

Current Understanding–During the period when the repository is operational, the ventilation system will contribute particulate matter from the atmosphere. After the repository is closed, fine debris from the host rock will settle onto the metallic surfaces. This debris is mainly expected to originate from rock dust that will contain the various mineral components of the tuff, plus any precipitated chemical species resulting from water seeping into the drift and the possible evaporation of salts dissolved in that water.

Dust minerals have deliquescent properties. When these minerals (salts) settle onto the metal drip shield or the waste package, they accumulate with continued exposure. As the temperature decreases in the repository, the relative humidity increases. Of concern to the drip shield and the waste package performance is the critical relative humidity above which a moisture film will form on the metal surfaces. It is at this point, corrosion processes can initiate on a metal surface since there is an electrolyte present and corrosion cells, with discrete anodes and cathodes, can be established. The deliquescent properties of the salts decrease the critical relative humidity at which an electrolyte is formed on the surface, and therefore, at which corrosion reactions can occur.

The deliquescent properties of salts are determined by its attraction to water molecules. Because of these attraction forces, salts that are highly deliquescent raise the boiling point of the solution. In some cases, the deliquescence and boiling point elevation are large. For example, calcium chloride is a highly deliquescent salt that lowers the critical relative humidity, and raises the salt's boiling point of concentrated solutions. Other salts show less pronounced effects.

The deliquescent properties of salt mixtures can be significantly different from the properties of the individual salts themselves, and nearly always, the deliquescence of the mixture is greater than that of the individual salts, meaning that the critical relative humidity is lower and the boiling point elevation is higher than that of the individual salts in the mixture. Much of the dust material is expected to be inert, in the sense that it has little or no effect on deliquescence. Silica, for example, is expected to have little effect on deliquescence. Thus, the composition of the dust material that falls and accumulates on the drip shield and waste package surfaces is important in predicting the future performance of these Engineered Barrier System components. Geochemical environments are complex due to the large number of chemical components and interactions among these components.

Baseline information and expected variability will be developed, obtained from the models and reports associated with in-drift physical and chemical environments, and later included in the PC Test Plans as it is developed for this work. Some of the corrosion rate parameters depend strongly on the chemical composition of solids (dust, salts from evaporated seepage) on the waste package (BSC 2004 [DIRS 167461]). In order to evaluate the effects of the dust deliquescence process, a field-sampling program was undertaken to characterize repository dust (Peterman 2001 [DIRS 165976]; Peterman et al. 2002 [DIRS 165975]; Peterman et al. 2003 [DIRS 162819]). Conditions of the waste packages entering the repository will be documented consistent with the calculation titled *Surveying and Removal of Radiological Contamination from External Surfaces of Waste Packages* (BSC 2004 [DIRS 168869]).

The major element compositions of the bulk dust samples were very similar to those of the repository host rock, indicating that the dust is dominated by finely comminuted (pulverized to powder) rock produced during tunnel excavation and construction activities (Peterman et al. 2003 [DIRS 162819]). Enrichments relative to the tuff wall rock in CaO, MgO, MnO, fluoride, and CO_2 are interpreted to be due to preferential comminution of fracture and cavity coatings (carbonates, manganese oxides hydroxides, fluorite) relative to the bulk tuff (Peterman et al. 2003 [DIRS 162819]). The enrichment of chlorine is likely related to salts derived from native pore water and construction water. Ferrous iron is enriched in the dust due to construction related ferrous metal particulates. Finally, measured organic carbon, up to a few percent of the total mass, has nonrock sources (soot and aerosols from diesel exhaust, abraded rubber and fiber from the conveyer belts, aerosols of hydraulic fluid, oil and greases, etc.).

Water-soluble anions and cations comprise only a tiny fraction of the bulk material, less than 0.5 percent of the total. Calcium, sodium, and potassium are the major cations in descending order of concentration, and sulfate, nitrate, and chloride are the major anions (carbonate was not analyzed). These compositions represent salts derived from evaporation of both native pore water and construction water. The construction water can be identified by the presence of Lithium Bromide, which was used as tracer in this fluid (Peterman et al. 2003 [DIRS 162819]). Bromide was also observed as a soluble constituent of dust. The compositions of the dust leachate are used in the model titled *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004 [DIRS 167461]) as input for determining the compositions of brines that might form by deliquescence on the drip shield and waste package, and under what conditions (relative humidity, temperature) those brines will occur.

Anticipated Methodology–This activity includes in situ monitoring, observation, laboratory analysis and field-testing. Samples exposed in the drift will be collected and analyzed to measure the actual salts that are present in the dust to assess (or refute) these predictions.

Although the concepts for this sampling have not yet been planned, and would not be finalized until waste emplacement, the technology will consist of using a remotely operated vehicle equipped with cameras and remote sampling devices. The cameras may be designed to provide a visual of the sampling activity. The remote sampling device would provide a mechanism to obtain the dust sample and transport it back to the surface for laboratory analysis.

The testing data are typically evaluated as results of dust composition that actually accumulates on the waste packages. Computer models account for a large number of interactive terms in order to predict the properties of water solutions containing multiple salts. These models predict behavior for the anticipated range of materials that will be present in the dust. These analytical results are compared to models that relate dust to corrosion of the waste package and drip shields. If the results from testing and monitoring exceeded a predetermined limit that would cause the modeled corrosion of the Engineered Barrier System components to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the sampling and monitoring is noninvasive and occurs in the drifts remotely. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.1.11 Thermally Accelerated Drift In-Drift Environment Monitoring

Activity Description–This activity includes 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 a thermally accelerated drift. Candidate parameters that may be measured include: temperature, relative humidity, gas composition, radionuclides, pressure and radiolysis, thin films evaluation, condensation water quantities, composition and ionic characteristics including microbial effects. This activity evaluates the potential environment that components of the Engineered Barrier System will endure. This long-term field collection and lab analysis activity provides relatively direct measurements. This is a new activity that will be conducted within the thermally accelerated drifts and will be initiated during operations, continuing until closure. As such, for the field-testing, the locations, durations, and design of the testing are very preliminary at this time. This monitoring will be conducted periodically at a frequency yet to be determined. Other methods and approaches may be employed and will be described in the PC Test Plans prior to waste operations.

Purpose–The purpose of this activity is to evaluate assumptions used in in-drift physical and chemical environment models. Characterization of the environment that surrounds the waste package container and drip shield supports evaluating the performance life times of these Engineered Barrier System 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 on the environmental conditions that will be measured in this activity.

Selection Justification–Because confirmation of the environment that immediately surrounds the Engineered Barrier System components is important for evaluating the performance life times of these components (the kinds of corrosion and the rates of corrosion are highly dependent on the environment), this in-drift environment monitoring activity is important.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, it is estimated that it is unlikely that the mean annual dose calculations would change if these parameter values are found to lie outside its current modeled range, possibly with the exception of the laboratory testing for water conditions (thin films, including microbial effects). In addition, if the range was exceeded, a change in these parameter values, including the microbial types and amounts, greater than that currently used as the range in the performance assessments, would likely change the selected conceptual models or require consideration of additional conceptual models. As such, if the results of this activity are not as anticipated, the implications on system performance could include a greater potential in the waste package corrosion failure mode and accordingly, a greater potential for Engineered Barrier System breach and radionuclide release to the Lower Natural Barrier.

For the reasons presented above, this activity is designed to meet the requirements of 10 CFR 63.131(a)(1) and (2), 10 CFR 63.132(a) and (b), and 10 CFR 63.133(a). Specifically, the activity addresses the requirement that the performance confirmation program provide data that indicate, where practicable, whether the 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 that the natural and engineered systems and components are functioning as intended and anticipated (e.g., corrosion due to environment). In addition, that a continuing program of surveillance, measurement, and testing be conducted to ensure that geotechnical and design parameters (e.g., environment) are confirmed. That subsurface conditions must be monitored and evaluated against design assumptions and that there be monitoring for the condition of the waste packages.

Current Understanding–This activity focuses on in-drift conditions and is a companion activity to the thermally accelerated drifts near-field monitoring and thermally accelerated drifts thermal-mechanical effects monitoring and will be conducted in the thermally accelerated drifts.

Three field thermal tests have been conducted to obtain a more in depth understanding of the thermal-hydrologic-mechanical-chemical coupled processes and to provide data for enhancing confidence in the model analyses. Those tests are the Drift Scale Test, Large Block Test, and the Single Heater Test. The tests were conducted in the Tptpmn; the Single Heater Test and the Drift Scale Test were conducted in situ (at Alcove 5 of the ESF) and the Large Block Test was conducted in a nearby outcrop located at Fran Ridge. Detailed descriptions of the Drift Scale Test, the Large Block Test, and the Single Heater Test can be found in the following reports: *Drift Scale Test Design and Forecast Results* (CRWMS M&O 1997 [DIRS 146917]), *Drift Scale Test As-Built Report* (CRWMS M&O 1998 [DIRS 111115]), *Large Block Test Final Report* (Lin, et. al. 2001 [DIRS 159069]), and the *Single Heater Test Final Report* (CRWMS M&O 1999 [DIRS 129261]). Results from characterizing the Drift Scale Test block are contained in the *Ambient Characterization of the Drift Scale Test Block* (CRWMS M&O 1997 [DIRS 101539]). Early results of the Drift Scale Test are discussed in the *Drift Scale Test Progress Report No. 1* (CRWMS M&O 1998 [DIRS 108306]) and *Thermal Testing Measurements Report* (BSC 2002 [DIRS 160771]). Thermal testing measurements for all three tests are reported in *Thermal Testing Measurements Report* (BSC 2002 [DIRS 160771]). Performance assessment process models that use these measurements are described in the following reports: *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 163056]), *Drift-Scale Coupled Processed (DST and THC Seepage) Models* (BSC 2004 [DIRS 168848]), *Drift Scale THM Model* (BSC 2004 [DIRS 167973]), and *Abstraction of Drift-Scale Coupled Processes* (BSC 2004 [DIRS 169617]).

This is a new activity. An established baseline is not available at this time, especially as it relates to conditions created by actual waste packages. Whereas thermally induced property monitoring activities have been conducted during site characterization in the ESF and ECRB Cross-Drift (although not remotely) and are currently ongoing, this specific performance confirmation activity will not begin until the thermally accelerated drift is constructed and waste packages emplaced. The references that may be consulted for this activity may include: *Drift Scale THM Model* (BSC 2003 [DIRS 164890]), *Drift Scale Coupled Processes (Drift Scale Test and THC Seepage) Models* (BSC 2002 [DIRS 158375]), and *Thermal Hydrological-Chemical (THC) and Thermal Hydrological (TH) Only Drift Scale Model Analysis* (DTN: SN0002T0872799.007 [DIRS 148605]), *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 168720], and *Multiscale Thermohdrologic Model* (BSC 2004 [DIRS 163056]). Data specifically from the Drift Scale Test will be used from the reports discussed in the previous paragraph.

Anticipated Methodology–General–This activity includes remote monitoring and sample collection. A remote monitoring device will be used to obtain the data required to evaluate the environmental conditions and assess types and rates of corrosion. These activities will be conducted within the thermally accelerated drifts and will be initiated during operations, continuing until closure. The following factors pertinent to each parameter discussion and anticipated methodology will be evaluated.

Description and Anticipated Methodology–Water–From the perspective of the Engineered Barrier System, the most important environmental parameter is water. Water is an electrolyte, and therefore essential in making possible the electrochemical reactions that lead to corrosion cell establishment on the surface of the drip shield or the waste package. The quantity of water that contacts these engineered components, and species that are contained within the water (especially the dissolved ionic species), are significant in determining the corrosion behavior of the drip shield and waste package. The water compositions are expected to vary with time and with location in the drifts. The other parameters that are to be measured in this activity influence either the time when water can access the surface of the drip shield or waste package, or the chemical characteristics of that water.

Description and Anticipated Methodology–Temperature and Humidity–The temperature around the waste package is expected to increase when the drift is closed. It is estimated that the maximum temperature will occur within 10 years of repository closure. Depending on how the waste packages are spaced in the repository, the peak temperature in the base case could be as high as 203°C on the waste package and as high as 282°C for low probability seismic collapse (DIRS 163056 Section 6.3.6 and 6.3.7). Water that percolates toward the drift is vaporized which generates mineral and salt precipitates. After reaching the maximum value, the temperature will slowly decrease. As the temperature decreases, the relative humidity increases. Eventually a point is reached at which the temperature is sufficiently low and the relative humidity is sufficiently high that a moisture film may form on the Engineered Barrier System surfaces. This point is dependent on the deliquescent properties of various dusts (Section 3.4.3) and the salts they contain.

The deliquescence of the salts reduces the critical relative humidity value above which an aqueous solution can form and the dissolution of salts in this solution can increase the temperature where this solution boils. It is expected that these solutions will be concentrated in salts and can be correctly called brines. There is a broad range of temperature and humidity over which these brines can form. In the absence of any salts, the boiling point of water at the elevation of the repository underground facility is 96°C. On a salt-free surface of Alloy 22, the critical relative humidity above which a moisture film can be sustained is approximately at 80 percent relative humidity. On a dust-coated surface, the critical relative humidity may be as low as 20 percent and the boiling point of the resulting brine may approximate 120°C. Below the boiling point of the brine, additional water percolating or seeping down through the rock can strike the drip shield, or fall directly on the waste package if the drip shield is not present, and collect on its surface. Variation of temperature around the waste package is expected. The temperature at the ends of the package will be 10°C to 15°C cooler than the central part of the package. Waste packages located at the ends of the drift will be cooler than those placed in the center of the drift. The temperature will decrease as the sensor is moved away from the waste packages toward the drift wall, but thermal convection and the presence of the invert will cause the atmosphere above the waste package to be at a different temperature than the atmosphere surrounding the lower portion of the waste package. The relative humidity would also vary spatially in the atmosphere around the waste package. This variation in temperature and humidity has implications on the placement of witness samples in the thermally accelerated drifts (Section 3.4.5).

Description and Anticipated Methodology–Atmospheric Gases–Water composition is influenced by atmospheric gases, particularly carbon dioxide, which tends to equilibrate with the carbonate and bicarbonate that is present in many of the waters associated with the site. These species influence the pH of the solution. Oxygen in the atmosphere is also important because it helps to establish the dissolved oxygen content in the water, which in turn, helps to establish the oxidation potential (Eh) of the solution. These properties significantly affect the corrosive characteristics of the water.

Description and Anticipated Methodology–Ionic Salts–The ionic concentrations of species dissolved in the water affect the corrosion behavior of the metals. These species also influence the pH and Eh, and in addition, some species are aggressive toward breaking down the passive films that normally protect metals like Alloy 22 and titanium alloys. Other species are also notable for favoring passive film formation and are said to be corrosion inhibitors. Thus, the ratio of aggressive to inhibitor ions is an important parameter. With regard to predicting corrosion behavior, water chemistry is a complex subject because of interactions of the various species dissolved in the water.

In general, a chloride ion is nearly always more aggressive toward promoting corrosion than other ions; the chloride ion attacks the metal at locations where the passive film is weakest and the result is localized corrosion, which most often occurs in creviced areas. On the other hand, a nitrate ion inhibits corrosion for metals and restores passivity. Chloride and nitrate act as opposing ion pairs, and since they are the most soluble of the anions that are present in nearly all the waters associated with the site, their effect on corrosion is the most important. They are present in an approximate 0.5 nitrate to 1.0 chloride ratio in most of the waters. Other ionic species that are usually present in the waters include anionic species of carbonate and bicarbonate, which tend to make the water more alkaline, which favors passivity. Carbonate dominated waters have good pH buffering properties, so the alkaline pH typical of these waters is maintained. Sulfate is another less aggressive anion found in nearly all the site waters tested. It appears to have some corrosion inhibiting properties, compared to chloride.

Nearly all the site waters contain silicate and are usually saturated with silicate. This ion tends to make solutions more alkaline and it may have some buffering effect, although not as pronounced as that of carbonate. On the other hand, the site waters contain fluoride, which can be an aggressive species toward titanium alloys and Alloy 22 in some cases as well. The effects of fluoride, as with chloride, are most prominent in more acidic solutions. However, fluoride salts are not as soluble as chloride salts, and therefore usually less available to concentrate.

The cations in the water also influence the potential corrosivity of the water. The main concern is the relative amounts of alkali species (i.e., principally sodium and potassium) and alkaline earth (i.e., calcium and magnesium) species. In many instances, the calcium and magnesium salts are less soluble than the sodium and potassium salts, so they do not buildup to as high a concentration. In some cases, the alkaline earth salts are quite insoluble. However, chlorides of the alkaline earth elements are among the most aggressive reagents for promoting localized corrosion and stress corrosion cracking on many metals and alloys. These chlorides become quite soluble with an increasing temperature, and also raise the boiling point considerably (Section 3.3.4.2). They are aggressive because of their high concentrations of chloride and because of hydrolysis of these solutions to acidic values of pH.

In the mixed ionic salt solutions, which are believed to be the most dominant of water chemistries that will contact the Engineered Barrier System, the other ions tend to counteract the effect of the halide ions, chloride and fluoride. Many additional ionic species will be present, mainly at very small concentrations, because of water contact with the mineral assemblage in the rock. Most of these species can be regarded as spectator ions that have little or no particular effect on the corrosion behavior of the Engineered Barrier System materials. Potentially damaging species, such as heavy metal ions, are believed to be confined to small concentrations in the water and will not concentrate because of their very low solubilities in the brines that will develop on the container surfaces. Analysis of waters collected in the drifts during performance confirmation is intended to confirm or refute the previous discussion.

Description and Anticipated Methodology–Microbial Species–Microbes (i.e., bacteria and fungi) can live in a dormant state as spores for indefinitely long periods of time until favorable conditions for their propagation arrive in the repository. The most important factor is water. Microbes need liquid water for their life processes. Beyond water, they need a nutrient and an energy source, and (usually) chemical species in the water to provide these sources. There are a vast number of species, and each species has a range of environmental conditions in which it thrives. Microbes survive and propagate even in extreme environments of high temperature and high salt concentrations. Yucca Mountain has many species of microbes that are native and it is expected that excavation and construction of the repository, plus the operations conducted at the site, including the ventilation of the drifts, will introduce additional species. Microbes can colonize on metal surfaces and form biofilms. The biofilms often comprise different microbial species that form an ecological system creating chemical gradients across the biofilm. Microbes can colonize on metal surfaces and form biofilms. The biofilms often comprise different microbial species that form an ecological system creating chemical gradients across the biofilm. Thus, in the presence of biofilms, it is possible for the metal surface to be exposed to a reducing environment even through the prevailing exposure condition is oxidizing as it will be at Yucca Mountain. In addition, the pH and the concentration of various ionic species can also vary across the thickness of the biofilm. In addition, the pH and the concentration of various ionic species can also vary across the thickness of the biofilm.

The main concern is what the chemical conditions on the metal surface are. Certain species of microbes produce acids and chemical species corrosive to many metals. Alloy 22 and titanium alloys have excellent resistance to a wide range of pH and chemical conditions, but there are limits. To date, information in the technical literature and data from the Project experimental laboratory work suggest that microbially influenced corrosion will not be a performance limiting process in the Yucca Mountain setting.

The objective of collecting microbial samples in the thermally accelerated drifts is to identify the total counts of microbes and the speciation of these counts to determine how they compare with previously acquired microbe populations taken from the ESF, and to determine how these samples compare with microbe populations that have been used in testing activities.

Description and Anticipated Methodology–Radiolysis–Gamma radiation penetrating through the waste package container can produce chemical changes in the environment (annual dose reduction provided by the waste package shell is addressed in *Commercial SNF Waste Package Design Report,* (BSC 2004, [DIRS 168217] Section 2, Appendix B, Tables B-1 and B-2). The main concern occurs when gamma radiation is simultaneously present with water so that chemical species potentially damaging to the waste package are formed. The thickness of the waste package significantly mitigates the amount of gamma radiation that penetrates through it, and the strength of the gamma field decreases with time as the radioactive material in the waste decays. Radiolysis decomposes water into its constituents, oxygen and hydrogen, plus a number of short-lived radicals and some metastable products such as hydrogen peroxide. In addition, species dissolved in the water can be oxidized or reduced, and atmospheric gases can be oxidized or reduced as well. The major concern is the oxidation products, because the main reduction product under aqueous conditions is hydrogen gas, which readily escapes from the repository drifts. Some of the oxidation products can be harmful to waste package performance since they raise the corrosion or open circuit potentials. On the other hand, moderately oxidizing conditions are generally of benefit to Alloy 22 and titanium alloys because they promote and retain passivity of the materials.

The strength of the gamma field is expected to be reduced by the time aqueous conditions will occur, so that radiolytic effects on the environment are expected to be small, and consequently, the effects on the material performance will be small. The objective, therefore, of measuring the gamma field strength and its effects on the environment and on witness test samples emplaced in the drift, is to confirm or refute the previous discussion.

Whereas laboratory analysis and sampling activities in the ESF similar to those described above have been conducted during site characterization, this specific performance confirmation activity will not begin until the thermally accelerated drift is constructed and waste packages emplaced. This activity includes in situ monitoring, laboratory and field-testing that would be conducted periodically, on a frequency yet to be determined, and documented in the PC Test Plan. Baseline information and expected variability will be developed, obtained from the models and reports associated with in-drift environments, and later included in the PC Test Plans as they are developed for this work.

The testing data are typically evaluated as results of chemical and physical conditions in the drift that would impact the waste packages, drip shields, and other engineered materials. These results are compared to models that relate in-drift conditions to corrosion of the waste packages, drip shields, and other engineered materials (for example, rails, ground support structures, and waste pallets). If the results from testing and monitoring exceeded a predetermined limit that would cause the modeled performance of the Engineered Barrier System components to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity includes remote monitoring and sample collection and is not expected to adversely affect the ability of the repository to meet performance objectives as the sampling and monitoring is noninvasive and occurs in the drifts remotely. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.2 Geotechnical and Design Monitoring and Testing

The repository performance confirmation program includes a continuing program of surveillance, geotechnical testing, and geologic mapping to confirm geotechnical and design parameters. Implementation of this aspect of the performance confirmation program will occur during construction and operations and includes thermally accelerated drift thermal-mechanical monitoring (Section 3.3.2.4)

3.3.2.1 Subsurface Mapping

Activity Description–This activity includes mapping of fractures, faults, stratigraphic contacts, and lithophysal characteristics. Candidate parameters that may be measured include: fracture characteristics, fault zone characteristics (offset, location, age), stratigraphic contacts, and lithophysal characteristics. This long-term field observation program provides a direct measurement of in situ conditions that represent the spatial scale over the area of the repository. This activity supports evaluation of the performance of the Upper and Lower Natural Barriers in the vicinity of the repository drifts and mains by confirming that the stratigraphic sequences and rock properties actually exist within the ranges as modeled in the Integrated Site Model. This activity will begin soon after underground construction begins and will be conducted more or less continuously as new drifts, mains, and shafts are mined. Mapping can only occur as new underground openings are exposed. Mapping will end soon after the last mined opening is finished.

Purpose–The purpose of this activity is to evaluate results from integrated site models. Underground geologic mapping 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 Yucca Mountain repository. Documentation of fracture characteristics, fault zone characteristics, lithostratigraphic contacts, and lithophysal characteristics provides a background for confirming: (1) appropriateness of designed ground support components, (2) short and long-term stability of emplacement and nonemplacement openings, (3) predicting the effects of thermal loading on the walls of the emplacement drifts, (4) near-field hydrologic characteristics of the emplacement drifts, and (5) the presence of anomalous infillings which might have deleterious effects on waste isolation characteristics of the repository.

Selection Justification–Mapping of repository excavations ensures that any variations from the expected geologic conditions (e.g., lithology, lithophysal characteristics, fracture characteristics, unexpected structural features) described in the License Application are documented. Fractures provide the majority of the permeability of the rock; however, in lithophysal-bearing zones, these cavities contribute dramatically to the hydrologic and mechanical behavior of the rock. If the conditions vary widely from the range expected, the conceptual models may not change, but it may be necessary to reevaluate the rate of water movement because stratigraphic sequences, rock properties and mineralogy in the vicinity of drifts account for about 50 percent of the calculated range in performance assessment.

There is high confidence that the modeled range of this parameter will not be exceeded and that a change in the parameter values greater than those currently used as the range in the performance assessments would not change the selected conceptual models or require consideration of additional conceptual models. This long-term field observation program provides a direct measurement of in situ conditions that will stay the same during both the preclosure period and the compliance period but will likely vary spatially. There is very high confidence that the observations and measurements represent the spatial scale over the area of the repository.

For the reasons presented above, this activity is designed to meet the requirements of 10 CFR 63.131(a)(1) and (2), and 10 CFR 63.132(a), (b), and (c). Specifically, the activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether the 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 that the natural and engineered systems and components are functioning as intended and anticipated. In addition, that a continuing program of surveillance, measurement, and testing and geologic mapping be conducted to ensure that geotechnical and design parameters (e.g. environment) are confirmed and that subsurface conditions must be monitored and evaluated against design assumptions and the 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*.

Current Understanding–The Integrated Site Model merges the detailed Project stratigraphy, collected from surface mapping, boreholes, and underground mapping into model stratigraphic units that are useful for constructing the primary subsequent models and the repository design. The integrated site model was developed to provide a consistent portrayal of the rock layers, rock properties, and mineralogy of the Yucca Mountain site. The Integrated Site Model consists of three components:

- *Geologic Framework Model (GFM2000)* (BSC 2002 [DIRS 159124])
- *Rock Properties Model Analysis Model Report* (BSC 2002 [DIRS 159530])
- *Mineralogic Model (MM3.0) Analysis Model Report* (BSC 2002 [DIRS 158730]).

The *Geologic Framework Model (GFM2000)*, (BSC 2002 [DIRS 159124]) represents a three-dimensional interpretation of the geology surrounding the repository site at Yucca Mountain. The geologic framework model encompasses an area of 65 mi^2 (168 km^2) and a volume of 185 mi^3 (771 km^3). The boundaries of the geologic framework model were chosen to encompass the exploratory boreholes and to provide a geologic framework for hydrologic flow and radionuclide transport modeling through the unsaturated zone over the site area. The depth represented by the model is constrained by the inferred depth of the Tertiary Paleozoic unconformity. The geologic framework model was constructed from geologic map and borehole data. Additional information from measured stratigraphic sections, gravity profiles, and seismic profiles was also considered.

The *Geologic Framework Model (GFM2000)*, (BSC 2002 [DIRS 159124]) provides a baseline representation of the locations and distributions of rock layers and faults in the subsurface of the Yucca Mountain area, for use in geoscientific modeling and repository design. The input data from geologic mapping and boreholes provide controls at the ground surface and down to the total depths of the boreholes; however, most of the modeled volume is unsampled and with attendant uncertainty. The geologic framework model is an interpretative and predictive tool that provides a representation of reality within the estimated uncertainty.

The *Rock Properties Model Analysis Model Report* (BSC 2002 [DIRS 159530]) provides exhaustive, three dimensional, discretized, numerical representations of several important hydrologic and thermal rock properties (porosity, bulk density, matrix saturated hydraulic conductivity, and thermal conductivity) that are intended for use in numerical design and performance assessment analyses. The composite modeling units defined for this analysis encompass the majority of the rocks within the unsaturated zone in the immediate vicinity of the repository at Yucca Mountain.

The *Mineralogic Model (MM3.0) Analysis Model Report* (BSC 2002 [DIRS 158730]) models the abundance and distribution of minerals and mineral groups within stratigraphic sequences in the Yucca Mountain area, for use in geoscientific modeling and repository design. The mineralogic model is, therefore, an interpretation and a prediction tool rather than an absolute representation of reality. The model possesses an inherent level of uncertainty that is a function of data distribution and geologic complexity. Uncertainty in the model is mitigated by the application of sound geologic principles.

The baseline for mapping will be derived from the integrated site models above, with detail of mapping not captured at the scale of the drifts and mains supplemented from results in the previous geologic mapping in the ESF and ECRB Cross-Drift. These include: *Geology of the North Ramp - Station 0+60 to 4+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada* (Beason et al. 1996 [DIRS 101191]); *Geology of the North Ramp — Stations 4+00 to 28+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada* (Barr et al. 1996 [DIRS 100029]); *Geology of the Main Drift - Station 28+00 to 55+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada* (Albin et al. 1997 [DIRS 101367]); *Geology of the South Ramp - Station 55+00 to 78+77, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada* (Eatman et al. 1997 [DIRS 157677]); and *Geology of the ECRB Cross Drift - Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada* (Mongano et al. 1999 [DIRS 149850]).

Anticipated Methodology–This activity includes field mapping of fractures, faults, stratigraphic contacts, and lithophysal characteristics and very limited sampling for laboratory examination (e.g., thin section examination, mineralogical, or chemical analysis). In the emplacement drifts, geologic mapping will be performed once each drift is completed and the tunnel boring machine and its components are removed from the drift. Construction utilities will be removed and the drift crown, walls, and invert thoroughly cleaned with a specially designed, high-pressure air and water system. The drift walls will then be completely photographed using high-resolution digital cameras, and the images stitched together to produce a full-periphery digital mosaic of the drift surface. These mosaics will be transferred to a hand-held computer where the fracture locations can be traced onto the photos. Orientation and special characteristics (such as noting if the fracture is a shear or fault, and sense of offset) will be recorded for each fracture. A suite of fracture characteristics (planarity, infilling, roughness, aperture, terminations, etc.) will also be recorded for the fractures along one wall of the drift. Fault characteristics will be noted including amounts of offset (where determinable), thicknesses and types of fault breccia and rubble, angularity and size of clasts, infilling, zonations within the breccia and rubble, cementation, etc. Lithostratigraphic contacts and lithophysal characteristics will also be collected. Geologic mapping will be followed by the installation of permanent ground support and other drift preparation.

In nonemplacement drifts, a similar mapping technique will be used, but the mapping may be done on or immediately behind the trailing gear of the tunnel boring machine. Cleaning of the walls will also be necessary in these excavations to remove the tunnel boring machine smear from the walls, and to help mitigate dust concerns during excavation. Mapping will be coordinated with the excavation operation to minimize interference. The sequencing of construction operations and mapping will be different than in emplacement drifts. Data from mapping will probably be collected with the permanent ground support in place because less detailed geologic information is needed for nonemplacement drifts due to their lesser importance to an evaluation of waste isolation capability.

In shafts, geologic data will also be collected in a similar fashion, using overlapping digital photos as the base upon which fracture traces are digitized. Data collection will be nearly identical in scope and detail to that in the horizontal nonemplacement drifts, except that the collection will be performed from the bottom deck of the shaft sinking Galloway or from a specially-designed mapping platform suspended from the shaft support infrastructure.

The geologic mapping data are typically evaluated as maps of repository excavations. Comparison of these maps with integrated site models ensures that variations from the expected geologic conditions (e.g., lithology, lithophysal characteristics, fracture characteristics, unexpected structural features) described in the License Application are documented and provide the basis for an evaluation of their potential impact on the understanding of barrier or system performance. If the variation from expected conditions exceeded a limit, an evaluation of the potential problems (drift and main stability, changes in assumptions incorporated into Upper and Lower Natural Barrier models, or thermal response characteristics) would be conducted and reported as described in Section 4.

This activity will not adversely affect the ability of the repository to meet performance objectives because the mapping is noninvasive including observations and documentation of features already exposed by the tunnel boring machine. Sampling of rock is very minor. The effects of the wall cleaning are very short lived and induce a very small amount of water into the rock very early in construction. The wetting effects have been shown, during past mining operations, to dissipate almost immediately and are reversed by drying induced by ventilation. Construction effects greatly outweigh any impacts related to this activity. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.2.2 Seismicity Monitoring

Activity Description–This activity includes monitoring regional seismic activity. It also includes observation of subsurface and surface (large magnitude) fault displacement after significant local or regional seismic events. Candidate parameters that may be measured include: event detection, event magnitude, event location, strong-motion data collection and analysis, and seismic attenuation investigations (within 50 km). This activity addresses disruptive influence that could impact the lifetime of the Engineered Barrier System as a result of seismic events. This long-term field data collection activity provides direct measurements that represent the temporal and spatial scale over the area of the repository during the monitoring period. Seismic monitoring began during site characterization. The existing seismic monitoring system–will be maintained through closure of the repository.

Purpose–The purpose of this activity is to evaluate annual probability distribution as a function of intensity. The activity is designed to assess the regional seismic activity that is assumed in simulations of the seismic disruption scenario. These simulations suggest that large widespread failures of the waste packages may result from accelerated, localized corrosion caused by extensive rockfall from large-scale drift degradation resulting from very large seismic events. Waste forms may also experience failure resulting from shaking from very large seismic events. Seismic parameters for nominal earthquakes (i.e., location, size, style, and number) will continue to be collected continuously during construction and operation of the repository using automated equipment. Field observation data will be collected for any large magnitude fault displacements that occur after any significant local or regional seismic event.

Selection Justification–This activity is important because the effects of potential mechanical interactions between the drip shield and waste package under rockfall and seismic conditions are an uncertainty in performance assessment models.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, there is high confidence in the current understanding of the very low probability of large seismic events and the robustness of the geologic framework at the repository horizon for not being impacted by seismic activity. There is confidence that the modeled range of this parameter will not be exceeded. However, a change in the parameter value greater than that currently used as the range in the performance assessments would cause the Project to reevaluate the selected conceptual models or require consideration of additional conceptual models.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(1), (2), and 10 CFR 63.132(a). Specifically, this activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether 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 whether natural 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. 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. This activity focuses on the surveillance of seismicity and observations of highly unlikely events to evaluate whether designed systems are operating as anticipated.

Current Understanding–The assessment of seismic hazards at Yucca Mountain focuses on characterizing the potential vibratory ground motion that will be associated with future earthquake activity in the vicinity of the site. The evaluation of these hazards serves as a basis to define inputs for the preclosure seismic design of a geologic repository (BSC 2003 [DIRS 166274]). The evaluation also provides information that can be used to assess the impact of future seismic activity on the ability of the repository to meet the performance objectives for the postclosure period.

Seismic hazards at Yucca Mountain are assessed probabilistically (YMP 1997 [DIRS 100522]). The assessment is founded on the evaluation of a large set of data pertaining to earthquake sources, fault displacement, and ground motion propagation in the Yucca Mountain region. The data set contains information about prehistoric earthquakes on nearby Quaternary faults. The historical earthquake record and information on the attenuation of ground motion are also important components of this data set. Tectonic models that have been proposed for the Yucca Mountain area and information from analogue sites in the Basin and Range Province provide the basis to characterize the patterns and amounts of fault displacement. The probabilistic assessment explicitly incorporates uncertainties in the characterization of seismic sources, fault displacement, and ground motion. The resulting hazard calculations thus represent a sound basis for seismic design and performance assessment by reflecting the interpretations that are supported by data, along with the associated uncertainties in those interpretations.

Monitoring seismic activity provides the means to evaluate the historic earthquake information distribution and spectra. If the distribution or spectra or observations of fault displacements after seismic events were different than assumed in the probabilistic assessment, it would cause the Project to reevaluate the selected conceptual models and possibly reevaluate the assessment.

The baseline for this activity and the history of seismic monitoring is described in more detail in CRWMS M&O (2000, [DIRS 151945] Section 12.3.3.1) and von Seggern and Smith (1997 [DIRS 159532]). A catalogue of historical and instrumental earthquakes was compiled for the region within 300 kilometers of the repository site at Yucca Mountain (CRWMS M&O 1998, [DIRS 103731] Appendix G). Catalogue completeness has improved significantly with time, but the catalogue is still considered to be complete only for historical events of M_w 5.5 and larger within the 100 kilometer radius around Yucca Mountain since 1868 (Rogers et al. 1991, [DIRS 106702] p. 166).

Anticipated Methodology–Consistent with operation of the existing seismic network, seismometers and digital recorders are deployed in the area to be monitored. Stations are distributed uniformly, with a higher density of stations closer to Yucca Mountain to enable the detection of smaller earthquakes and to provide better control in estimating the depths of earthquakes that occur in that area. Data from the monitoring stations are transmitted to a central recording site using digital telemetry. At the central recording site, data are recorded, analyzed, and archived.

When significant events (those that exceed a predetermined threshold) are detected within 50 kilometers of the site, geologists will travel to the event site and survey the area for evidence of surface displacement. If present, the amounts and directions of offset, including surface displacement, will be documented. Additionally, geologists will examine known underground fault traces for evidence of movement. Observations regarding any fallouts or wedge failures will also be made. Examination of selected emplacement drifts will be done remotely, concentrating on the locations of the known faults.

Data analysis includes identification of earthquakes, location of earthquakes, and determination of their size. In addition, for earthquakes that are sufficiently well recorded, the type of faulting is determined. An evaluation of the earthquake probability would be established based on historical data and sensitivity of performance assessment models. If the probability exceeded a predetermined limit, an evaluation of the potential impact on the understanding of the repository system would be conducted and reported as described in Section 4.

This activity will not adversely affect the ability of the repository to meet performance objectives because the monitoring is noninvasive and occurs at the surface with some stations underground. Additionally, seismicity-monitoring activities do not result in the introduction of any materials that could affect the performance of the repository. If new methods are proposed in the future, further evaluations on waste isolation and test-to-test interference will be conducted during the revised test planning.

3.3.2.3 Construction Effects Monitoring

Activity Description–This activity includes instrumenting the mined openings to detect construction deformation. Candidate parameters that may be measured include: drift convergence, tunnel stability, and engineered ground support systems. Geotechnical rock properties may be evaluated at selected locations. This activity supports evaluation of the performance of the Upper and Lower Natural Barriers in the vicinity of the repository drifts and mains by confirming the mechanical properties. This long-term field observation program provides a direct measurement of in situ conditions that will likely vary spatially.

This activity began during site characterization and will continue during construction. Monitoring in drifts will cease when nuclear waste is emplaced. Long-term monitoring in mains and shafts is expected to continue until closure.

Purpose–The purpose of this activity is to evaluate tunnel stability assumptions under ambient conditions. The deformations will be monitored prior to waste emplacement. Geotechnical parameters, if determined to be necessary to understand the mechanical responses, would be collected at selected locations representative of rock properties from the subsurface mapping activity (Section 3.3.2.1). Since this activity will occur prior to emplacement of nuclear waste, mechanical responses at ambient temperatures will be monitored. These mechanical responses will be mainly deformations, which can be used to determine rock mass moduli. Because temperature gradients will be minimal, rock-mass coefficient of thermal expansion will not be determined.

Selection Justification–Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, it was determined that there is high confidence in the current understanding of the geologic framework and rock properties that control drift stability at the repository horizon. There is high confidence that the modeled range of this parameter will not be exceeded and that a change in the parameter values greater than that currently used as the range in the performance assessments would not change the selected conceptual models or require consideration of additional conceptual models. If the conditions vary widely from the range expected, the conceptual models would not change, but it may be necessary to reevaluate the effect of drift instability in the vicinity of drifts. Drift geometrics and potential drift collapse account for about 50 percent of the calculated range of seepage in performance assessment.

For the reasons presented above, this activity is designed to meet the requirements of 10 CFR 63.131(a)(1) and (2); 10 CFR 63.132(a), (b), and (c); and 10 CFR 63.133(a). Specifically, the activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether the 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 that the natural and engineered systems and components are functioning as intended and anticipated. In addition, that a continuing program of surveillance, measurement, and testing and geologic mapping be conducted to ensure that geotechnical and design parameters (e.g., environment) are confirmed and that subsurface conditions must be monitored and evaluated against design assumptions and the 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*. During the early or developmental stages of construction, a program for testing engineered systems and components used in the design will be instituted.

Current Understanding–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 gages (installed on steel sets), tunnel (vertical and horizontal) convergence pins, MPBXs (installed in the local rock), single-point borehole extensometers (SPBXs) (installed in the local rock), and rock bolt load cells.

The baseline information for this activity will be synthesized from information obtained from reports, mainly *Drift Degradation Analysis* (BSC 2004 [DIRS 168550]), and design specifications. In addition, other references may include: *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (BSC 2003 [DIRS 166183]); *Supporting Rock Fall Calculation for Drift Degradation: Quantification of Uncertainties* (BSC 2001 [DIRS 158207]); *Drift Degradation Analysis* (BSC 2004 [DIRS 168550]); *Evaluation of Emplacement Drift Stability for KTI Resolutions* (BSC 2004 [DIRS 168889]); and *Supporting Rock Fall Calculation for Drift Degradation: Drift Reorientation with No Backfill* (CRWMS M&O 2000 [DIRS 149639]).

Anticipated Methodology–The deformations will be monitored prior to waste emplacement. Most measurements will use similar measuring devices and systems to those previously described, with an emphasis on deformational monitoring. Plans for construction monitoring of rock mass response in the repository main and emplacement drifts consider experience acquired during construction monitoring of deformations in the ESF and ECRB Cross-Drift (BSC 2004, [DIRS 169734] Section 3.6.6.3). These measurements will provide a quantitative measure of drift stability. In addition, rock mass moduli will be determined from these deformations by using calculated or assumed loading along these excavated drifts. It is unlikely that temperature gradients will be significant during this preemplacement period. Therefore, determination of thermal-elastic rock mass properties such as the coefficient of thermal expansion will not be determined. Also, it is anticipated that camera and laser observations and monitoring of drift deformations will be conducted during this preemplacement period to assess or shakedown these measurement techniques. This approach will increase the reliability of deformational measurements planned for emplacement drifts after waste emplacement.

The data analysis evaluates preemplacement deformational measurements to evaluate, for early times, mechanical models used to predict drift stability in the emplacement and main drifts. Also, rock mass, isothermal mechanical properties will be determined for each of the repository host rock units. This comparison of measurements with the baseline information will indicate whether the ranges for the parameters measured in situ are consistent with the data used as the basis for the conceptual models and the ranges used for the input parameters for the numerical models relevant to drift stability. A summary of results is contained in the *Yucca Mountain Site Description* (BSC 2004, [DIRS 169734] Section 3.6.6.3). If the conditions vary from the range expected, it may be necessary to reevaluate the effect of drift instability in the vicinity of drifts. This would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the instrumentation is very small and covers an insignificant portion of the rock in the repository. Construction effects resulting from the mining activities greatly outweigh any impacts related to this monitoring of construction effects activity. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.2.4 Thermally Accelerated Drift Thermal-Mechanical Monitoring

Activity Description–This activity includes monitoring drift and invert degradation in the thermally accelerated drifts. Candidate parameters that may be measured include: drift convergence, drift shape, drift degradation, ground support visual condition, rail alignment, invert visual condition, pallet visual condition, waste package alignment, and spacing. Results from this activity will be used to assess the potential environment that components of the Engineered Barrier System will endure during the performance confirmation period. This long-term remote field monitoring provides a direct measurement where the relevant time-dependent processes for the repository are captured in the measurement. This is a new activity that will be conducted within the thermally accelerated drifts and that will be initiated during operations, continuing until closure. As such, for the field-testing, the locations, durations, and design of the testing are very preliminary at this time. This monitoring will be conducted periodically at a frequency yet to be determined. Other methods and approaches may be employed and will be described in the PC Test Plans prior to waste operations.

Purpose–The purpose of this activity is to evaluate drift degradation assumptions and analyses under thermal conditions. These deformations, which will be measured remotely, will be used to assess the degradation and mechanical-stability of these two features, thus providing an indication of overall drift stability.

Selection Justification–This activity is focused on assessments of drift stability that in turn, have impacts on the environment which Engineered Barrier System components will endue in the repository. Mechanical loading from rockfall rubble accumulated from drift degradation over time may lead to failure of the drip shields and waste packages. The failure of these Engineered Barrier Systems will depend on the rate of accumulation of rubble in the drift and the threshold load-bearing capacity of the systems. The accumulation in the drift outside the systems will increase the waste package temperatures and may affect water seepage into the drifts. As such, this activity is important to collect data for drift stability modeling and has impacts on models for seepage and thermal processes within the drifts.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, it was determined that there is confidence that the modeled range of these parameters will not be exceeded during the compliance period. If the conditions vary widely from the range expected, the conceptual models would likely not change, but it may be necessary to reevaluate the effect of drift instability in the vicinity of drifts. Drift geometrics and potential drift collapse affect the calculated range of seepage in performance assessment. This long-term remote field monitoring provides a direct measurement in which there is moderate confidence that the relevant time-dependent processes for the repository are captured in the measurement.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(1) and (2); 10 CFR 63.132(a), (b), and (c); and 10 CFR 63.133(a). Specifically, the activity addresses the requirement that the *Performance Confirmation Plan* must identify the geotechnical and design parameters to be measured or observed (drift and invert degradation). The plan must provide data that indicate, where practicable, whether 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 that it provide data that indicate, where practicable, whether the 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. This activity is also designed to assess, through surveillance and measurements, that during repository construction and operation, geotechnical and design parameters are within the bounds of the design assumptions. In addition, this activity serves as in situ monitoring of the thermal-mechanical response of the underground facility to be conducted until permanent closure, to ensure that the performance of the geologic and engineering features is within design limits and that during the early and developmental stages of construction, a program for testing of engineered systems and components used in the design, such as, thermal interaction effects of rock, are being conducted.

Current Understanding–This activity is a follow-on to the construction effects monitoring (Section 3.3.2.3) and the drift inspection activity (Section 3.3.1.8) under thermal conditions. 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 gages (installed on steel sets), tunnel (vertical and horizontal) convergence pins, MPBXs (installed in the local rock), SPBXs (installed in the local rock), and rock bolt load cells.

This is a new activity. An established baseline is not available at this time, especially as it relates to conditions created by actual waste packages. Whereas thermally induced property monitoring activities very similar to this have been conducted during site characterization in the ESF and ECRB Cross-Drift (although not remotely) and are currently ongoing, this specific performance confirmation activity will not begin until the thermally accelerated drifts are constructed and waste packages emplaced. The references that may be consulted for this activity may include: *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (BSC 2003 [DIRS 166183]); *Supporting Rock Fall Calculation for Drift Degradation: Quantification of Uncertainties* (BSC 2001 [DIRS 158207]); *Drift Degradation Analysis* (BSC 2004 [DIRS 168550]); *Evaluation of Emplacement Drift Stability for KTI Resolutions* (BSC 2004 [DIRS 168889]); *Supporting Rock Fall Calculation for Drift Degradation: Drift Reorientation with No Backfill* (CRWMS M&O 2000 [DIRS 149639]); *Drift Scale THM Model* (BSC 2003 [DIRS 164890]); *Drift Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2002 [DIRS 158375]); *Thermal Hydrological-Chemical (THC) Thermal Hydrological (TH) Only Drift Scale Model Analysis* (DTN: SN0002T0872799.007 [DIRS 148605]); and *Thermal Testing Measurements Report* (BSC 2002 [DIRS 160771]).

Anticipated Methodology–This technology consists of remote monitoring by equipment with both cameras and lasers. The cameras may be designed to provide stereographic views and projections of the drift wall and invert such that deformations within the drift are better observed. This stereographic capability is important because most of the anticipated deformations would occur inward, especially along the rib where horizontal thermal-elastic stresses steadily increase as the thermal pulse from the emplaced waste packages has a continual effect. Lasers can provide additional observations and deformation monitoring along the periphery of the thermally accelerated drift and the invert. A number of extensometer-based and other techniques are being considered.

It is anticipated that camera and laser observations and monitoring are to be initially conducted on monthly intervals during the initial phase (i.e., up to 3 years) of the accelerated drift test. Monitoring frequency is likely to be reduced after this initial period, especially if deformations are consistent with numerical predictions. Measurements may provide some indication of the crushed tuff invert deformational behavior. Further evaluation of methods is required.

Measurements of vertical closure and horizontal closure are part of the ongoing Drift Scale Test in the ESF (BSC 2004, [DIRS 169734] Section 5.4.5). However, these types of convergence measurements may not be possible with waste packages in place. In addition, postemplacement high-temperature and high-radiation environments will require development of technology for these applications. Planning for this activity is preliminary in nature; other methods and approaches may be employed and will be described in the PC Test Plans prior to waste operations.

The monitoring data are typically evaluated as results of changes in in-drift configuration in response to the thermal pulse. These results are compared to models that relate thermal-mechanical-hydrologic-chemical behavior of the rock of the Upper and Lower Natural Barriers as they relate to postclosure drift stability. If the results from testing and monitoring exceeded a predetermined limit that would cause the modeled rock properties of the Upper and Lower Natural Barrier in the near-field to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity is not expected to adversely affect the ability of the repository to meet performance objectives because the instrumentation is superficial to the drift wall and the remote techniques will not affect the waste packages or in-drift conditions. If drilling is used to emplace instrumentation, it will be very limited and occurs in a very small portion of the drift. The amount of rock that may be disturbed is of such insignificant amount as to not impact the pathway of water reaching the drifts, especially during the periods after closure. However, before closure, it may be possible to remotely seal the boreholes, as appropriate, if analytical and modeling results indicated that the small boreholes would increase seepage potential. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.3 Design Testing (Other Than Waste Packages)

The repository performance confirmation program includes geotechnical testing to evaluate the effectiveness of design parameters for closures and seals to be installed as part of permanent repository closure. The only activity currently in this group is seal testing.

This activity tests the effectiveness of engineered system components including borehole and shaft seals, and seals and backfill used as a seal or closure material in access drifts and ramps. In addition, it evaluates whether natural and engineered systems and components required for repository operation, and that are designed or assumed to operate as barriers after permanent closure, will function as intended and anticipated.

3.3.3.1 Seal Testing

Activity Description–This activity includes laboratory testing of borehole seal effectiveness field-testing of ramp and shaft seals effectiveness, and field testing of backfill placement and compaction procedure effectiveness. Candidate parameters that may be measured include borehole seals materials, configuration, performance, shaft seals materials, ramp seals materials, laboratory and field hydraulic and pneumatic seal effective permeability. This laboratory analysis and field-testing activity provides direct measurements and indirect observations. This activity is principally related to regulatory requirements, but supports evaluation indirectly of the performance of the Upper and Lower Natural Barriers. This is a new activity to the Project. Seal testing will be initiated during construction and early stages of emplacement. Testing backfill procedures will be conducted during repository operations. As such, for the field-testing, the locations, durations, and design of the testing are very preliminary at this time.

Purpose–The purpose of this activity is to evaluate design assumptions for effective seals. The purpose of closing and sealing of the repository access drifts is to provide for long-term stability of the repository. Shaft, ramp, and borehole seals are designed to limit water intrusion into the repository. Backfill is included to enhance repository stability. Seal effectiveness criteria that will be evaluated include that seal and closure systems must be mechanically, chemically, geologically, and thermally compatible with the subsurface environment. Backfill placement and compaction procedures will be evaluated against design requirements.

Selection Justification–Seal testing is an important activity because seals and backfill are components installed for repository closure which contribute to: precluding human intrusion; limiting preferential pathways for water towards the emplacement drifts; precluding magma flow between drifts in the unlikely igneous disruptive event scenario; and enhancement of overall stability of nonemplacement drifts.

This activity was not included in the risk-informed, performance-based activity selection approach described in Section 1.4.1. However, this activity is designed to meet the requirements 10 CFR 63.133(a), (c), and (d), but also help support the objectives of 10 CFR 63.131(a)(2). Specifically, this activity addresses the requirements that during the early or developmental stages of construction, a program for testing of engineered systems and components used in the design, such as borehole and shaft seals, must be conducted. 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. Also, testing to evaluate effectiveness of backfill placement and compaction procedures must be conducted before beginning permanent backfill placement. In addition, it must be evaluated whether 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.

Current Understanding–Boreholes will be sealed and capped with a concrete (or alternate material) plug (or plugs) at preselected locations. Shafts and ramps will be sealed at selected locations, backfilled, and capped with concrete at the portal. Access drifts and the entrances to emplacement drifts are anticipated to be backfilled and plugged with an appropriate closure material. Backfill material will be crushed tuff; and concrete seals will be designed for seismic loads, loading from host rock stress relief, and loading from the tuff backfill. The key to the sealing program is that the seal performance does not have to exceed that of the intact rock.

The performance confirmation program for testing engineered systems and components used in the design will be developed as early as practicable during construction. It will include evaluation of materials and design for the borehole, shaft, and ramp seals. Laboratory seal testing and testing to evaluate placement of granular materials is a common engineering activity for subsurface openings and waste disposal sites so numerous standards and methodologies exist. These existing standards and methodologies will be evaluated before testing begins for applicability to the needs of Yucca Mountain. Planning for this activity is preliminary in nature; other methods and approaches may be employed and will be described in updates to this plan.

Laboratory testing of borehole seals will involve the conduct of comprehensive tests on seal materials and configurations under a relatively wide range of performance conditions. This wide data range (wide distribution) should allow good comparisons against current parameter expectations. Appropriate adjustments can then be made to seal designs and to performance expectations.

Shaft and ramp seal testing will be more complex. An established baseline specific to Yucca Mountain is not available at this time. But as noted above, analogue information for the performance, testing and analysis of seals is widely available in the engineering literature. Criteria for shaft and ramp seal locations include placement of the seal at the interface between highly fractured rock and relatively unfractured rock. This criterion could position the seal at a location at which flowing water would be drained into the host rock where its movement would then be attenuated by the matrix flow in the relatively unfractured rock. In any event, onsite (in situ), large-scale shaft and ramp seal testing will provide relevant data for performance evaluations. Again, testing can be conducted under a wide range of conditions and there will be ample time to compare results with performance expectations; make appropriate adjustments to designs or performance models, or both.

Design specifications and candidate configurations are presented in: *Subsurface Closure & Seal System Description Document* (CRWMS M&O 1999 [DIRS 103086]); *Closure Seal Locations and Geologic Environment Study* (CRWMS M&O 2000 [DIRS 144992]); *Closure Seal Materials and Configuration* (CRWMS M&O 2000 [DIRS 145033]); *Closure and Sealing Preliminary Design Calculation* (BSC 2004 [DIRS 166604]); *Repository Design, Closure and Sealing Typical Details* (BSC 2001 [DIRS 158464]); and *Repository Closure and Sealing Approach* (CRWMS M&O 2000 [DIRS 150624]).

Sealing of shafts, ramps and boreholes will be conducted as part of closure of the repository. Closure of the repository also includes removal of materials and backfilling of underground openings (except emplacement drifts). Field-testing to evaluate effectiveness of backfill placement and compaction procedures will be conducted prior to placement of backfill. Planning for these components of the activity is not developed; methods and approaches that may be employed and will be described in the PC Test Plan.

The ramps and shafts seals design, and backfill design may change as more detailed information becomes available from detailed geologic mapping during construction. During construction mapping, locations for seal testing may be determined.

Anticipated Methodology–In addition to the considerations noted above, laboratory testing of borehole seals will be conducted on cored boreholes through intact tuff samples collected from alcoves in both welded and nonwelded tuff. Air permeability testing will be used to test the grout seal and surrounding rock. Field-testing of shaft and ramp seals may be conducted in large diameter openings that originate from alcoves or the observation drift, in full-scale drifts, or in comparable rock formations outside the repository footprint. Testing will be designed to monitor and evaluate water drainage by shaft seals and the ability to seal the surrounding damaged zone around shaft and ramp openings. Tests designed to evaluate the effectiveness of borehole, shaft, and ramp seals will be conducted before sealing these penetrations, as part of repository operations. Field tests will be used to evaluate the effectiveness of backfill placement and compaction procedures, against design requirements. The testing data are typically evaluated as permeability values and water drainage results. These results are compared to design specifications on performance. If the results from testing and monitoring exceeded a predetermined limit that would cause the seals to fail, an evaluation of the potential impact would be conducted and reported as described in Section 4. It is likely that the seals would be redesigned and retested to meet design criteria.

The laboratory portion of this activity cannot adversely affect the ability of the repository to meet performance objectives, because this is a series of laboratory tests conducted offsite. The field-testing portion of this activity is not expected to adversely affect the ability of the repository to meet performance objectives because the testing occurs in a very small portion of the drifts cross section and is expected to occur outside of the repository footprint where waste is to be emplaced. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning. Integration with Design and Engineering to define the underground layout will be conducted during the detailed test planning.

3.3.4 Monitoring and Testing of Waste Packages

Performance confirmation activities include provisions for laboratory testing of waste package, waste package pallet, and drip shield materials representative of those emplaced in the repository. These performance confirmation activities focus on corrosion testing of waste package, waste package pallet, and drip shield materials, as well as internal waste conditions. To the extent practical, the laboratory experiments will be designed to be representative of the repository emplacement environments. These laboratory tests will be used to confirm the design basis for the waste package and to confirm information that supports modeling of waste package, waste package pallet, and drip shield performance. The waste package monitoring program includes corrosion monitoring, but is not limited to the use of corrosion coupons.

Activities designed principally to provide information relevant to these objectives are:

- Waste package monitoring (Section 3.3.4.1)
- Corrosion testing (Section 3.3.4.2)
- Corrosion testing of thermally accelerated drift samples (Section 3.3.4.3)
- Waste form testing (Section 3.3.4.4).

The waste package monitoring activity is a new activity that will begin after waste emplacement. It will be focused on examination of representative packages in situ in the repository.

These corrosion testing activities, which continue the laboratory performance confirmation begun during site characterization, will continue during repository construction and operation. The focus is on the fabrication materials for the waste packages, waste package pallet, and drip shields in the environments relevant to evaluating the performance of these components. Testing for waste package, waste package pallet, and drip shield materials is presented in this section because of the similarities in the testing approaches.

The corrosion testing activity consists of laboratory-based tests that are a continuation of the laboratory corrosion testing currently in progress. The laboratory testing environments may be modified as appropriate. The corrosion testing of thermally accelerated drift samples will involve exposure of test samples in the thermally accelerated drifts with subsequent sample characterization and analyses performed in the laboratory. The tests on samples exposed in the thermally accelerated drifts are designed to provide corrosion information in addition to the corrosion behavior measured from exposure of test samples in the laboratory environments.

The principal objective of corrosion testing activities is determination of general corrosion rate and an evaluation of the overall corrosion performance of the waste package outer barrier material, waste package pallet material, and the drip shield material. Laboratory testing consists of general corrosion testing, phase transformation testing, localized corrosion testing and stress-corrosion cracking testing. General corrosion testing includes passive current density, weight loss measurements, passive film composition, microbial effects, and mechanical properties.

Qualitative and semi-quantitative information about resistance to localized corrosion and to environmentally accelerated stress corrosion cracking will be obtained. Localized corrosion and stress corrosion cracking are not expected to occur in the laboratory test environment or in the thermally accelerated drifts environment for materials planned for waste package and drip shield. Tests will be conducted to confirm this expectation. The stability of the Alloy 22, Type 316 stainless steel, and titanium alloys passive film maintains very low general corrosion rates and provides protection from localized corrosion and environmentally accelerated stress corrosion cracking. Analyses of the passive film structure and composition are intended to evaluate predictions made from thermodynamic calculations of passive film stability.

Waste form testing is ongoing, and has focused on bare fuel, cladded fuel and high level waste glass testing. This waste form testing is a new activity. The new waste form testing activity focuses on waste form testing in the laboratory under internal waste package conditions and includes waste package and waste form coupled effects.

3.3.4.1 Waste Package Monitoring

Activity Description–This activity includes remote monitoring for evidence of external corrosion of the waste package. Candidate parameters that may be measured include: external visual corrosion and possibly internal pressure of the waste package. This long-term remote field monitoring provides a direct measurement. This activity directly evaluates the performance of the waste package as a major component of the Engineered Barrier System. This is a new activity that will be initiated during the early stages of emplacement operations. Planning for this activity is preliminary in nature; other methods and approaches may be employed and will be described in the PC Test Plans prior to waste operations.

Purpose–The purpose of this activity is to evaluate waste package integrity and confirm the absence of leakage and leak paths. The test would be applied to a set of selected, representative waste packages. Testing may be conducted using remote monitoring for external corrosion or using technology to sense the differential pressure between the waste package interior and outer sections.

Selection Justification–This activity is focused on directly observing waste package performance, which in turn has a direct impact on the Engineered Barrier System performance. The intact waste packages can protect the waste form from dripping water. However, the Engineered Barrier System SSCs may be compromised by various degradation processes, including corrosion and mechanical damage, therefore, it is important to observe them during this period to assure their performance. Because waste packages are a key component of the Engineered Barrier System, if the waste packages degrade much faster than is currently planned, the Engineered Barrier System will be much less effective and would require a reevaluation of barrier capability and a resulting analysis of the impact on waste package performance assessment models.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, it was determined that there is high confidence that the calculated range will not be exceeded. If a change in the parameter value exceeds the range currently used in the performance assessment, that change is anticipated to be sufficiently small that it will not change the selected conceptual models or require consideration of additional conceptual models.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2) and 10 CFR 63.134(a). Specifically, the activity addresses the requirements that the performance confirmation program must provide data that indicate, where practicable, whether the engineered systems and components (waste packages) are functioning as intended and anticipated and that a program be established 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.

Current Understanding–Contact between water and the waste form and cladding is prevented as long as waste packages are intact. Water flow and potential radionuclide movement are limited even after the waste packages are breached. The waste packages have a dual-metal design consisting of two concentric cylinders. The inner cylinder is made of a thick shell of Stainless Steel Type 316 with additional restrictions on carbon and nitrogen. The outer cylinder is made of a shell of Alloy 22, a corrosion-resistant, nickel-based alloy. Alloy 22 protects the stainless steel inner cylinder from corrosion, and the Stainless Steel provides structural support for the thinner Alloy 22 cylinder. The corrosion rates for anticipated repository conditions of Alloy 22 are so low that it is not expected that packages will be breached by general corrosion or stress corrosion cracking during the regulatory compliance period. Analyses of the potential for early breach of waste packages by processes other than corrosion (e.g., improper heat treatment or damage by rockfall) indicate a low probability that packages will be breached during the compliance period. Even after that time, the slow breach rate of packages and the low rate of water movement through them limits releases of radionuclides for many tens of thousands of years.

The baseline information for this activity will be synthesized from TSPA-LA results as well as from information obtained from analysis and modeling reports. The information will be obtained from the most recent versions of the following reports: *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier* (BSC 2001 [DIRS 155640]); *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2003 [DIRS 164475]); *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003 [DIRS 161317]); *Probability Analysis of Corrosion Rates for Waste Package Materials* (BSC 2004 [DIRS 169356]); *Aging and Phase Stability of Waste Package Outer Barrier* (BSC 2003 [DIRS 162199]); *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003 [DIRS 166834]); *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003 [DIRS 161236]); *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2004 [DIRS 169042]); and *Hydrogen Induced Cracking of Drip Shield* (BSC 2003 [DIRS 161759]).

Anticipated Methodology–The field waste package monitoring, including the number of packages monitored, locations, durations, and design of the testing, are very preliminary at this time. It is expected that inspection of selected representative waste packages to evaluate the integrity of the engineered systems and the design assumptions will be conducted periodically. Because changes are expected to be slow, if at all, inspection may be conducted yearly or less frequently. This monitoring and inspection will consist of visual observation of the waste package conditions and may include future technologies to sense the differential pressure between the waste package interior and outer sections.

Waste packages selected for underground monitoring will be representative of different configurations as well as different environmental conditions that may exist underground such as in areas with differing rock thermal conductivities and different placement in the drifts (for example, near the ventilation entrance as well as the exit to examine effects temperature and humidity differences).

Current methodologies that are known to be feasible and not impact performance would include remote visual inspection for corrosion and differential pressure sensing (i.e., waste package internal pressure compared to external pressure). Pressure sensing may require the installation and operation of magnetic sensing (or alternative) devices mounted on or within the waste packages. However, because of the regulatory requirement that performance confirmation activities not adversely affect the performance capability of the repository, there is a concern that the installation and operation of devices on the waste package could affect its integrity. Further evaluation is required due to the risk of such adverse effects.

The data are typically evaluated as visual indicators of unexpected corrosion or loss of internal pressure. The corrosion of the waste package materials is one of the more important features of the Engineered Barrier System. If the results from visual observation or the loss of internal pressure exceed predetermined limits that would cause the anticipated failure rate for waste packages or source term assumptions to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

The visual observation activity will not adversely affect the ability of the repository to meet performance objectives because the visual monitoring is noninvasive and occurs in the drifts remotely. If future planning requires placing sensors directly on or through the waste packages, an analysis or determination of impact will be conducted to evaluate if the instrumentation could affect the integrity of the package as compared to noninstrumented packages. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.4.2 Corrosion Testing

Activity Description–This activity includes laboratory corrosion testing of waste package, waste package pallet, and drip shield samples in the range of representative repository environments. Candidate parameters that may be measured include: Alloy 22, Type 316 stainless steel, and titanium alloys (Grade 7 and 24) mass loss rate, passive current density, surface dissolution, open circuit potential, critical potential, stress crack corrosion, microbial effects, surficial passive film stability, and mechanical properties. This long-term laboratory testing provides direct measurements of corrosion of materials used in the Engineered Barrier System. Laboratory exposure of waste package, waste package pallet, and drip shield samples in the range of potential repository thermal and chemical environments (including simulated radiolysis and inoculated microbial effects), followed by appropriate characterization and analyses to determine rates and the kind of corrosion, and the morphology of corrosion attack. The planned laboratory testing consists of three areas:

A. Corrosion test facility
B. Thermal aging facility
C. Electrochemically-based testing.

This activity directly evaluates the materials performance of the waste package as a major component of the Engineered Barrier System. This activity (testing and analysis) is conducted in the laboratory. The activity began during site characterization and the planned work is a continuation of work that has been underway for several years and will continue for several years or decades into the future. Test environments will be adjusted, as appropriate to reflect data obtained in the thermally accelerated drifts testing.

Purpose–The purpose of this activity is to evaluate results of corrosion models. This is accomplished through measurements of the general corrosion rate and an evaluation of the overall corrosion performance of the waste package outer barrier material, waste package material, and the drip shield material. The samples are representative of the waste package, waste package pallet, and drip shield materials, including processes used to fabricate, assemble, weld, and stress relieve these materials.

Selection Justification–Understanding the corrosion modes of the Engineered Barrier System components is key to evaluating the Engineered Barrier System performance. This activity is very important in assessing the expected conditions and provides for evaluation of the Engineered Barrier System functionality.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a high potential impact on the performance of the total system. It is estimated that there is generally a high probability that the mean annual dose calculations would change if these parameter values were found to lie outside its current modeled range. There is general confidence that the modeled ranges for these parameters will not be exceeded during the compliance period. Mechanical properties of passive films are the exception with relatively lower confidence (BSC 2004 [DIRS 168504]). Phase transformations in Alloy 22 can have detrimental effects on the performance of the material in the repository environment, because some of the transformation products are richer in molybdenum and chromium–alloying elements important for imparting high corrosion resistance–and deplete the surrounding matrix of these elements. In some cases the transformation product is more brittle than the base alloy, and would lead to loss of fracture toughness (important if the waste package were subjected to seismic motion).

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2) and 10 CFR 63.134(c). Specifically, the activity addresses the requirement that the performance confirmation program provide data that indicate whether engineered systems and components are functioning as intended and anticipated and that the waste package monitoring program include laboratory experiments that focus on the internal condition of the waste packages.

Current Understanding–The significance of general corrosion is that it is the background degradation mode. Both Alloy 22 and titanium alloys (Grade 7 and 24) were selected for their anticipated very low general corrosion rates in the expected repository environments. With respect to the waste package outer barrier, even at the highest measured general corrosion rate, the container wall would not be corroded through during the compliance period. However, more information besides general corrosion rates can be obtained from test samples exposed in laboratory environments. Qualitative and semi-quantitative information on resistance to localized corrosion and to environmentally accelerated cracking can also be obtained. These tests serve as the physical demonstration of this prediction. The analysis of the passive film structure and composition serves to evaluate predictions made from thermodynamic calculations of the passive film. It is the chemical, physical, and mechanical properties of the passive film that determine its stability, maintain very low general corrosion rates, and assure protection from localized corrosion and stress corrosion cracking.

Phase transformations of concern are of two types: formation of tetrahedrally compact phases that form rapidly at temperatures above 600°C and formation of an ordered phase that forms rapidly at temperatures above 500°C. The concern is whether these transformations will occur at the comparatively lower temperatures in the repository over much longer time periods. Existing models project that these transformations will not occur to a significant extent on the base metal, but there is more uncertainty on welded material and material that will be cold-worked as part of the stress relief process.

The baseline information for this activity will be synthesized from TSPA-LA results as well as from information obtained from reports. The information will be obtained from the most recent versions of the following reports: *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier* (BSC 2001 [DIRS 155640]); *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2003 [DIRS 164475]); *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003 [DIRS 161317]); *Probability Analysis of Corrosion Rates for Waste Package Materials* (BSC 2004 [DIRS 169356]); *Aging and Phase Stability of Waste Package Outer Barrier* (BSC 2003 [DIRS 162199]); *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003 [DIRS 166834]); *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003 [DIRS 161236]); *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2004 [DIRS 169042]); and *Hydrogen Induced Cracking of Drip Shield* (BSC 2003 [DIRS 161759]).

Anticipated Methodology (Part A)–Corrosion Testing–The objective of this part of the activity is to continue obtaining corrosion data from a series of planned interval tests that were begun several years ago in the test facility. In a planned interval test, a large number of samples are emplaced in the test vessels at the beginning of the test. At various time intervals, some of the samples are removed from the test vessel for evaluation and analyses. One of the evaluations is a measurement of weight loss that occurred during the time interval the sample was exposed to the test solution. If the corrosion is uniformly distributed over the exposed test sample area, the amount of general corrosion is proportional to the weight loss. Thus, the time dependence of the general corrosion is obtained by the determination of the corrosion rate in each of the several time intervals the samples were exposed and then removed. It is important to examine the surfaces of the test samples before and after exposure to the test solution in order to characterize the corrosion damage and whether the distribution of the damage is uniform or localized.

In addition to the weight loss samples, other types of samples have been emplaced in the same vessels of the test facility so that the susceptibility of Alloy 22, Type 316 stainless steel and titanium alloys to other forms of corrosion can be established. Some of these samples are intentionally creviced (i.e., the area underneath close fitting washers), so that if localized corrosion susceptibility is present for the material and environment combination, the susceptibility is readily apparent as a corrosion attack in the crevice. Similarly, plastically strained samples in the form of a U-bend are emplaced in the test vessels, so that if a stress corrosion cracking or a hydrogen-induced cracking susceptibility is present for the material and environment combination, the susceptibility is readily apparent as visible cracks in the U-bend region. Lastly, self-loaded stress corrosion test samples are emplaced in the facility. These give even more quantitative results because the crack characteristics can be related to the stress level in the sample. While stress relief (such as by laser peening) is expected to alleviate stress corrosion concerns in the waste package, some continuation of stress corrosion testing is proposed to demonstrate the high resistance of the waste package material in case difficulties arise with demonstrating that the laser peening (or alternative stress relief process) has indeed removed residual tensile stress.

These kinds of tests have a qualitative aspect (i.e., cracks are either present or not present; attack in crevices is present or not present), but some aspects can be made semi-quantitative to compare materials or to compare environments. For example, each washer contains several slots creating a number of possible crevice regions, so that the relative crevice corrosion susceptibility can be obtained by counting the number of regions that show attack. For the regions attacked, the depth of attack can be estimated. Similarly, for stressed U-bend samples, the number of cracks or the length of cracks can be used as a semi-quantitative index of the relative susceptibility to stress corrosion cracking; self loaded stress corrosion test samples provide quantitative data.

In addition, the surfaces of the samples in these long-term tests are studied to define the characteristics of the passive films that form on Alloy 22, Type 316 stainless steel, and titanium alloys over the exposure time. One of the major arguments in demonstrating that these materials are long enduring in the repository environment is that they form an adherent and coherent passive film, and that this passive film remains physically, chemically, and mechanically stable with time. Some properties of the passive film are expected to change with time because of interaction with the environment, but these changes are not necessarily detrimental to performance. It is important to capture the changes in properties during the performance confirmation period to confirm or refute projections to longer periods. Microbial activity has been observed in the corrosion test facility (the vessels are open to the atmosphere) and periodic counts of microbial activity are conducted so that significant contributions of microbial activity on corrosion can be assessed in the overall evaluation of materials.

Methods for corrosion testing follow standard practices of the American Society for Testing Materials, with modifications made to accommodate repository-specific conditions and requirements. Technical implementation procedures prescribe the specific test methods and procedures used to make up the test solutions. Much of the work in this activity is observation of exposed surfaces. The observations are made in stages. Sample surfaces are observed by optical microscopy over nearly all of the surface area. Depending on the features observed, the next step is to look at the same surfaces under electron microscopy for more detailed imaging of the surface morphology. An environmental scanning electron microscope is used for this examination. The electron microscope has surface analysis capabilities so that the composition of the surface can be measured. As needed, other surface analytical tools can be used to evaluate features (e.g., the structure and the change in composition as a function of depth). These surface analytical techniques include x-ray photoemission spectroscopy, Auger electron spectroscopy, and Raman spectroscopy.

Corrosion-related weight loss experienced by highly corrosion-resistant materials, such as Alloy 22, Type 316 stainless steel, and titanium alloy (Grades 7 and 24), is barely measurable on standard analytical balances. If proven acceptable, methods that are more sensitive may be employed for this testing.

The test facility has been in operation for over five years and only one sample set remains in the test vessels of the original population. As part of performance confirmation activities, a restocking plan for the corrosion test facility is in preparation. The vessels will be restocked with additional samples of Alloy 22, Type 316 stainless steel, and different grades of titanium alloys. In parallel with developments expected to take place on weld process evaluations, samples that have been welded by different processes will be added to the test facility in the future. Similarly, test samples taken from prototype waste packages, waste package pallets, and drip shields will be added to the test facility. Lastly, as part of the restocking plan, the current test environments are reevaluated in light of the progress that has been made on defining the environmental scenarios that will develop around the waste package, waste package pallet, and drip shield. It is expected that some additional test environments will be incorporated, such as more concentrated solutions with boiling points well above 100°C, as well as solutions with different ratios of nitrate to chloride ion to encompass a wider range of environmental conditions.

Anticipated Methodology (Part B)–Thermal Aging Facility–The thermal aging facility began operations in 1998. Currently, five furnaces are in operation and are maintained at constant temperatures (400°, 500°, 550°, 600°, and 650°C) in air. Several hundred samples have already been removed from the furnaces and examined for evidence of phase transformation and changes in mechanical properties. Several hundred samples are still being thermally aged. The thermal aging facility also provides test samples for other parts of this activity (Parts A and C) so that the effect of the range of metallurgical conditions can be determined in these testing efforts.

The planned methodology is to measure the amount of material transformed, usually specified as an area fraction or volume fraction of the total, by using a number of different quantitative metallographic and microscopic techniques. Scanning electron microscopy and transmission electron microscopy are the two techniques used for identifying phases. These microscopic techniques also have associated surface analytical capabilities so that the elemental composition of the phase can be determined. This is important for distinguishing between different phases that can form. Electron backscatter diffraction techniques can be used for further distinction between phases, since each phase has a unique crystal structure. Finally, corroborating evidence includes measurement of mechanical properties in some instances, since the formation of second phases hardens the metal. This is especially true for ordering reactions. In general, a protocol involving most of the aforementioned techniques is used to obtain a characterization of the structure.

Anticipated Methodology (Part C)–Electrochemically-based Testing–Electrochemically-based testing (i.e., measurements of potential and current) is particularly useful for determining localized corrosion susceptibility. It can also be used to provide alternative, and often more sensitive techniques to the weight-loss method for measuring general corrosion. In addition, it can be conducted in abiotic and biotic test environments to discern effects of microbially influenced corrosion. Polarization of potential from the open circuit potential also simulates the effect of radiolysis on the test solution. Because electrochemically-based testing is typically short-term (on the order of a day to a few weeks) in duration as compared to the testing conducted in a corrosion test facility (on the order of months to several years), many more experimental variables can be studied in a series of electrochemically-based tests to advance knowledge of the material performance in a repository setting. Electrochemically-based testing is readily amenable to factorial design experiments so that a more comprehensive analysis of multiple parameters can be conducted with a relatively small number of individual tests.

Electrochemically-based testing can be used to measure properties that have been identified as significant to the long-term performance of the waste package, waste package pallet, and drip shield materials, for instance the open circuit potential and the critical potential. These properties form the basis for some of the 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. There are a number of critical potentials associated with breakdown or dissolution of passive films on metals, and other critical potentials associated with reformation of the passive film or repassivation of the metal, and there are a number of specific electrochemical measurement techniques. The work that has been performed in preparing for the License Application (construction authorization) has used a wide variety of techniques, most of which are American Society for Testing and Materials-based with some modification for the particular circumstances for this project. It is expected that these will continue as part of the performance confirmation program.

The open circuit potential (this is also called the corrosion potential) has been found to change with time on the materials of interest. The change in open circuit potential is attributed to compositional changes in the passive film on Alloy 22, as the films age on the material surface. The evolution of the open circuit potential has been followed for several years on samples exposed in the test facility (Part A), and it is expected that this work will continue into the performance confirmation period in conjunction with the restocking of the test facility and introduction of new test environments into this facility.

The general protocol for electrochemical testing to determine localized corrosion susceptibility is first to perform a suite of potentiodynamic tests where the Eh applied to a test sample is scanned linearly from the corrosion or open circuit potential to beyond the various critical potentials, and the film is broken down. Then, the scan is reversed, because some of the critical potentials are obtained on the reverse scan, where the passive film is restored. The amount of hysteresis in the system is also an indication of localized corrosion susceptibility. The results from potentiodynamic tests are then used to determine where potentiostatic tests should be conducted. In a potentiostatic test, the applied potential is kept constant, and the current is measured. Since the potentiodynamic tests predict the potential regions where a metal should be completely passive and where it should be subject to localized corrosion attack, potentiostatic tests evaluate these predictions. Typically, the current decreases with time to a steady state value, but the current transient can be used to help quantify the degree of localized attack if the applied potential is above the critical value. Most of the testing is conducted on creviced samples, because crevice corrosion is believed to be a degradation mode that possibly affects Alloy 22 under extreme environmental scenarios.

Another electrochemically-based testing method that will be used is linear polarization. In linear polarization, the potential is scanned by a small amount (10 to 20 mV) from the corrosion potential. Linear polarization is used to measure the corrosion current (which for Alloy 22 and titanium alloys is the passive current density in most environments), from which the general corrosion rate is calculated. It is an alternative method to the weight loss method, discussed previously. Because quite small currents are measurable, linear polarization is a more sensitive technique and used when corrosion rates are very small. Linear polarization is especially useful for conducting tests on a large number of combinations of environmental and metallurgical conditions, expected in performance confirmation. Linear polarization is especially useful when working in environments in which microbes are inoculated for studying microbially influenced corrosion, because the amount of polarization is small and does not appear to adversely affect the life processes of the microorganisms.

While general corrosion is believed to be the background degradation mode for the drip shield and waste package in the preponderance of expected repository environments, models for the overall corrosion performance are governed by critical ion concentrations that define the windows of susceptibility to other corrosion modes, such as localized corrosion, where the rates of attack are much larger. The critical ion concentrations are determined by conducting potentiodynamic tests across a range of compositions and noting where the critical potentials are located. Thus, a series of polarization curves in different environments is needed to determine these critical ion concentrations. In many instances, the critical ion concentrations are really the critical ratios of concentrations, for instance, the ratio of nitrate to chloride, and the ratio of alkali ions (sodium + potassium) to alkaline earth ions (calcium + magnesium). Microbially influenced corrosion on metals is another phenomenon that initiates when a critical concentration of some aggressive chemical species is exceeded. Electrochemically-based testing is used to define the boundaries for the onset of this corrosion mode.

As stated earlier, a major advantage to electrochemically-based testing is that a large number of combinations of environments and metallurgical conditions can be investigated in a relatively short period of time. The long-term aging facility, discussed in (Part B) above, is a source for samples of different kinds of metallurgical structures. Another source of material for test samples comes from prototypes of the waste package container, waste package pallet (and eventually the drip shield) that will be manufactured in the coming years. As also stated earlier, many of the evaluations performed under the shorter-term electrochemically-based testing provide information on appropriate test conditions for the longer term testing, described in (Part A). Thus, the three components of laboratory testing work together.

Planning for the laboratory corrosion testing activity is preliminary; however, in contrast to other activities in this plan, this activity is much more near-term and a continuation of ongoing work. Therefore, more detail is given above about this activity.

The testing data are typically evaluated as corrosion rates under different scenarios. The corrosion rate of the waste package, waste package pallet, and drip shield materials are two of the more important performance related SSCs of the Engineered Barrier System. If the results from corrosion testing exceeded a predetermined limit that would cause the breach rate for waste packages and drip shields or source term assumptions to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This laboratory portion of this activity cannot adversely affect the ability of the repository to meet performance objectives because this is a series of laboratory tests conducted offsite.

3.3.4.3 Corrosion Testing of Thermally Accelerated Drift Samples

Activity Description–Corrosion analyses in the laboratory of waste package, waste package pallet, and drip shield samples from the thermally accelerated drifts in the range of representative repository environments. Candidate parameter measurements may include: Alloy 22, Type 316 stainless steel and titanium alloys (Grade 7 and 24) mass loss rate, passive current density, surface dissolution, open circuit potential, critical potential, stress crack corrosion, microbial effects, surficial passive film stability, and mechanical properties. This long-term field and laboratory testing provides direct measurements of corrosion of engineered materials that had been exposed to the conditions in the thermally accelerated drift test. As far as possible, the methodology for corrosion testing in the environment of thermally accelerated drifts and subsequent analysis and characterization of test samples from the thermally accelerated drifts will be conducted in a parallel manner with test samples exposed in the long-term corrosion testing facility under laboratory conditions (Section 3.3.4.3). This activity directly assesses the materials performance of the waste package as a major component of the Engineered Barrier System. The analysis and characterization of thermally accelerated drifts exposed samples will be conducted in a laboratory setting. The laboratory analyses will begin several years before waste packages are emplaced in the drifts and before in situ corrosion testing can begin in the thermally accelerated drifts.

Purpose–The purpose of this activity is to evaluate results of corrosion models. This is accomplished through measurements of the general corrosion rate and evaluation of the overall corrosion performance of the waste package outer barrier material, waste package pallet material, and the drip shield material. The activity will involve exposure of test samples in the thermally accelerated drifts with subsequent sample characterization and analyses performed in the laboratory. The samples will be representative of the waste package, waste package pallet, and drip shield materials (same materials as in the design), including processes used to fabricate, assemble, weld, and stress relieve these materials.

Selection Justification–Understanding the corrosion modes of the Engineered Barrier System components is key to evaluating the barrier performance. This activity is very important to assessing the expected conditions and provides for evaluation of the Engineered Barrier System functionality.

Based on results from the risk-informed, performance-based activity selection approach described in Section 1.4.1, this activity was determined to have a high potential impact on the performance of the total system. It is estimated that there is generally a high chance that the mean annual dose calculations would change if these parameter values were found to lie outside its current modeled range. There is general confidence that the modeled ranges for these parameters will not be exceeded during the compliance period. Mechanical properties of passive films are the exception with relatively lower confidence. In addition, if the ranges were exceeded, a change in the parameter value greater than that currently used as the range in the performance assessments would likely change the selected conceptual models or require consideration of additional conceptual models. This is the case for about half the measured parameters (e.g., surface dissolution, weight loss rate, phase transformations). As such, if the results of this activity are not as anticipated, the implications on system performance could include a greater potential for waste package breach and accordingly, a greater potential for Engineered Barrier System breach and radionuclide release to the Lower Natural Barrier.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2) and 10 CFR 63.134(c). Specifically, the activity addresses the requirement that the performance confirmation program provide data that indicate whether engineered systems and components are functioning as intended and anticipated and that the waste package monitoring program include laboratory experiments that focus on the internal condition of the waste packages.

Current Understanding–Testing under real repository conditions is the most desirable performance confirmation of the behavior of the waste package, waste package pallet, and potential drip shield materials. The "witness" test samples are emplaced near the actual waste package. These test samples will experience the same temperatures, relative humidities, dust accumulation, moisture deliquescence, and water dripping (if it occurs in the allotted time period) with the same salt concentrations that the waste package container surface would encounter.

The baseline information for this activity will be synthesized from performance assessment results as well as from information obtained from the most recent versions of the following reports: *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier* (BSC 2001 [DIRS 155640]); *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2003 [DIRS 164475]); *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003 [DIRS 161317]); *Probability Analysis of Corrosion Rates for Waste Package Materials* (BSC 2004 [DIRS 169356]); *Aging and Phase Stability of Waste Package Outer Barrier* (BSC 2003 [DIRS 162199]); *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003 [DIRS 166834]); *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003 [DIRS 161236]); *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2004 [DIRS 169042]); and *Hydrogen Induced Cracking of Drip Shield* (BSC 2003 [DIRS 161759]).

Anticipated Methodology–Testing in the Drifts–This activity targets exposure of test samples in the field, (i.e., in the thermally accelerated drifts environment). A large number of samples will be emplaced in the drift at the beginning of the test period and then will be removed according to a planned interval approach similar to that previously described for the corrosion test facility. The types of samples and the respective postexposure characterization and analyses of the samples are much the same as those proposed for the laboratory testing. The general arrangement proposed for the in-drift exposure is to create test locations at the entry, at the exit, and at the middle of a thermally accelerated drift. Test samples at these locations will be attached to the side rails of the waste package pallets. These test samples will serve as a "witness" sample, because they are exposed to the same thermal and chemical environment as the actual waste package, waste package pallet, and the drip shield. The intention is to make the laboratory component of the testing and the thermally accelerated drifts component as parallel as possible, so that direct comparisons can be made between results from the different exposure histories.

After exposure in the thermally accelerated drifts 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. The laboratory may be located in the vicinity of the Yucca Mountain repository or it may be located elsewhere. The protocol for sample withdrawal and characterization will also follow a planned interval approach, as described in Section 3.3.4.2 (A) under the corrosion test facility.

Anticipated Methodology–Characterization and Analysis in the Laboratory–With regard to observations for possible localized corrosion and environmentally accelerated cracking, test methods also follow the standard practices of the American Society for Testing Materials with modifications made to accommodate the Project-specific conditions and requirements. Several technical implementation procedures were written to cover specific test methods, as well as procedures for making up the test solutions. Characterization and analysis of samples exposed in the thermally accelerated drifts will be conducted by many of the same methods used for characterization and analysis of samples exposed in the Corrosion Testing Facility and described in Section 3.7.2 (Part A).

An important part of the test samples' characterization, whether exposed in a laboratory environment or in a drift at Yucca Mountain, is the determination as to whether the corrosion of these materials is uniform. This is determined by examination and analyses of the exposed surfaces. The general corrosion model is applicable for uniform attack; if localized attack is observed (e.g., at grain boundaries, in creviced regions, as random pits), then other models are applicable.

Planning for this activity is preliminary in nature; other methods and approaches may be employed and will be described in the PC Test Plans prior to waste operations.

The testing data are typically evaluated as corrosion rate under different scenarios. The corrosion rate of the waste package, waste package pallet, and drip shield materials is one of the more important attributes of the Engineered Barrier System. If the results from corrosion testing on samples exposed to thermally accelerated drift conditions exceed a predetermined limit that would cause the estimated breach rate for waste packages or source term assumptions to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

The laboratory portion of this activity cannot adversely affect the ability of the repository to meet performance objectives because this is a series of laboratory tests conducted offsite. The field portion of this activity is not expected to adversely affect the ability of the repository to meet performance objectives because the sampling and monitoring is noninvasive and occurs in the drifts remotely. Further evaluations on waste isolation and test-to-test interference will be conducted during the detailed test planning.

3.3.4.4 Waste Form Testing

Activity Description–This activity includes waste form testing (including waste package coupled effects) in the laboratory under anticipated in-package conditions. Candidate parameters that may be measured include: radionuclide release rate, dissolution, environmental and hydrochemical indicators (Eh, pH, colloid characteristics), bare waste form dissolution, fuel rod waste form dissolution, including cladding degradation, failure and unzipping rate, and waste form and waste package performance under coupled chemical environments. This long-term laboratory testing provides direct measurements of waste form performance under internal waste package conditions. This activity assesses the source term for radionuclides derived from the waste form, which are potentially able to leave the waste package and be transported out of the Engineered Barrier System. Elements of waste form testing began during site characterization. This site characterization testing included fuel and fuel rod segment degradation and radionuclide release testing, waste form colloids characterization and concentration studies, and flow-through dissolution testing. This is an activity where some analytical elements were begun during site characterization, expanded to take place in a simulated waste package, and will continue until at least the early stages of waste emplacement. Planning for this activity is preliminary in nature; other methods and approaches may be employed and will be described in the PC Test Plan prior to waste operations. This activity is designed to support performance confirmation for the TSPA-LA nominal, seismic, and igneous intrusion scenarios.

Purpose–The purpose of this activity is to evaluate results of waste form degradation models and evaluate in-package expected conditions. This is accomplished by monitoring water accumulation from humid air exposure, water chemistry, and the mobile fractions of annual dose-critical radionuclides; in a laboratory test using commercial spent nuclear fuel and high-level radioactive waste glass inside two breached waste package mockups within a humidity chamber. Monitoring potential couple effects with waste package internal elements to include its internal surface material will also be evaluated. After refinements and improvements to the technical bases for the safety case (Hamilton-Ray 2004 [DIRS 172321]), if it is determined that in the igneous eruptive case that the waste package damage is extensive, then waste form testing could confirm assumptions about sorption onto corrosion products, diffusion characteristics and pathways, and water compositions representative of basaltic derived solutions that are important in the igneous intrusion scenario in TSPA-LA. Waste form testing could also confirm assumptions about water chemistry resulting from conditions assumed in the igneous intrusion scenario in TSPA-LA. This could include testing water compositions representative of basaltic derived solutions.

Selection Justification–The coupled nature of waste package source-term processes prevents the details of the process from being estimated with accuracy. One outcome of this is that large uncertainties are associated with the waste package source term models that will be relied on during licensing. The performance confirmation program will evaluate if waste package source-term processes are within the uncertainty range used in the License Application. The performance confirmation activities will likely reduce the uncertainty, by explicitly considering the cross coupling and other factors not considered to remain conservative.

Understanding the waste package source-term processes is essential to evaluating the Engineered Barrier System performance. This activity is very important to providing evaluation of the Engineered Barrier System functionality. The dissolution rate of the waste form in an aqueous environment is significant to waste isolation. Uncertainty in the dissolution rate is large such that the time required to release radionuclides from the waste forms can vary from hundreds of years to hundreds of thousands of years. Water chemistry and temperature within the waste package could affect the degradation rate of the spent nuclear fuel and vitrified wastes. Corrosion of the internal metallic components of the waste package could reduce pH, leading to higher dissolution rates. The water chemistry and especially pH will have a significant effect on reduction, sorption, and mechanisms that may significantly reduce the radionuclide release rate from a failed waste package. In addition, it is important to evaluate if there are processes that could potentially occur within a waste package that would cause it to corrode from the inside out, thereby, breaching the waste package and compromising the Engineered Barrier System capability.

Considering the risk-informed, performance-based selection approach described in Section 1.4.1, this activity has a high potential impact on the understanding of the performance of the total system. It is estimated that there is generally a high probability that the mean annual dose calculations would change if these parameter values were found to lie above their current modeled range. There is generally high confidence that the modeled ranges for these parameters will not be exceeded during the regulatory compliance period. In addition, if the ranges were exceeded, a change in the parameter value greater than that currently used, as the range in the performance assessments, would likely change the selected conceptual models or require consideration of additional conceptual models. As such, if the results of this activity are not as anticipated, the implications on system performance could include a greater potential for Engineered Barrier System breach and radionuclide release to the Lower Natural Barrier.

For the reasons presented above, this activity addresses the requirements of 10 CFR 63.131(a)(2) and 10 CFR 63.134(c). Specifically, the activity addresses the requirement that the performance confirmation program provide data that indicate engineered systems and components are functioning as intended and anticipated and that the waste package monitoring program include laboratory experiments that focus on the internal condition of the waste packages.

Current Understanding–The waste forms that will be disposed at Yucca Mountain include spent nuclear fuel and vitrified high-level radioactive waste. Both of these are solid materials that will degrade slowly in the unsaturated environment of the repository. Spent nuclear fuel primarily consists of heavy metal oxides of uranium, plutonium, and other radionuclides. High-level radioactive waste consists of a borosilicate glass containing radionuclides. The release of radionuclides from the waste form is further limited by the low solubilities of most radionuclides in the unsaturated, oxidizing environment of the repository. Even if waste packages are breached, release rates may be slow because the degradation rates of spent nuclear fuel and borosilicate glass are slow and the release of radionuclides will be dispersed over thousands of years. Because of their low solubilities and their tendency to sorb onto minerals, only a small fraction of the radionuclide inventory (mainly the mobile radionuclides technetium and iodine) is transported out of the repository. Even then, technetium located in the five metal phases of the fuel may not be readily released under repository-relevant conditions. The majority of the radionuclides do not move out of the repository environment.

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 will trigger a series of coupled and nonlinear processes dominated by degradation of fuel and steel components inside the package. The interacting processes are collectively termed "waste package source term coupled processes" and must be effectively predicted as they largely control the availability of: (1) water in the waste package; (2) the pH in the package and invert; and (3) by extension, the solubility and colloid mobility of annual dose critical radionuclides. Testing may also verify that the cladding does not pit or fail from creep (time dependent deformation) at waste package temperatures that are below 350 degrees C. It could also verify that splitting of the cladding will probably not occur under repository conditions.

The baseline information for this activity will be synthesized from TSPA-LA results as well as from information obtained from reports. The information will be obtained from the most recent versions of the following reports: *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004, [DIRS 167321] Section 7.1); *Defense HLW Glass Degradation Model* (BSC 2004 [DIRS 167619]); *DSNF and Other Waste Form Degradation Abstraction* (BSC 2003 [DIRS 163693]); *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003 [DIRS 166845]); and *Geochemical Interactions in Failed Co-Disposal Waste Packages for N Reactor and Ft. St. Vrain Spent Fuel and the Melt and Dilute Waste Form* (BSC 2002, [DIRS 160161] Section 7.1)).

Anticipated Methodology–This activity includes waste form testing (including waste form/package coupled effects) in the laboratory under internal waste package conditions. In the course of a series of tests under repository-like conditions within the performance confirmation period using scale mockups of breached waste packages, starting with small scale and ending with large scale tests involving actual waste forms, the actual water accumulation from humid air exposure, the water chemistry, and the mobile fractions of annual dose-critical radionuclides will be measured. This will provide relevant data for waste package source-term model evaluation. Data, which would be indicators of corrosion of the internal metallic components of the waste package, will also be measured. Those corrosion processes could, in turn, reduce pH, leading to higher dissolution rates and affecting the ability of radionuclides to be sequestered by alteration and corrosion products.

DOE has authorized BSC to make improvements and refinements in the technical bases that support the SAR (Hamilton-Ray 2004 [DIRS 172321]). Part of that scope is to evaluate disruptive igneous consequence modeling related to waste package damage by an igneous intrusion and waste form pulverization by an igneous eruption and make model changes as warranted. Currently, the igneous intrusion scenario includes potential changes in water chemistry that may result from contact with incoming basalt rather than rock types existing in Yucca Mountain. If the results from these improvements suggest that performance confirmation testing is still warranted, the potential for damage to waste form resulting from these conditions may be confirmed by enhanced performance confirmation testing. Water chemistries calculated from equilibrium with basaltic mineral assemblages may need to be confirmed against results from laboratory testing of basalts that would fill the emplacement drifts above the degraded waste package and drip shield. Basaltic flow-through column tests could also aid in confirming assumptions.

Some of the simulations may include specific emphasis on sorption onto stationary phases (corrosion products), diffusion characteristics and pathways, and water compositions representative of basaltic derived solutions to confirm assumptions used in the igneous intrusion scenario in TSPA-LA.

The test data are typically evaluated for dissolution rate. The dissolution rate of the waste form in an aqueous environment is important for radionuclides. Since water chemistry and temperature within the waste package could affect the degradation rate of the spent nuclear fuel and vitrified wastes, as well as, corrosion of the internal metallic components of the waste package that could in turn reduce pH, leading to higher dissolution rates these various effects will be studied and compared with model outputs. In addition, these values will also be compared with model result expected ranges. If the results from waste form testing exceed a predetermined limit that would cause the modeled transport properties of radionuclides or source term estimates of performance to be incorrect, an evaluation of the potential impact on the understanding of system performance would be conducted and reported as described in Section 4.

This activity will not adversely affect the ability of the repository to meet performance objectives because this is a series of laboratory tests conducted offsite.

3.4 PERFORMANCE CONFIRMATION FACILITIES

Performance confirmation activities will be performed in a number of physical locations. Some will occur on the surface, some underground prior to and after emplacement, and some in a laboratory. Many of the planned new activities are related to the coupled effects after emplacement. A new test bed, described as the thermally accelerated drifts, is a major emphasis of new testing and monitoring for performance confirmation and is discussed separately.

3.4.1 Surface Activities

Extensive surface-based testing of the unsaturated zone and saturated zone hydrologic characteristics at Yucca Mountain has been conducted (CRWMS M&O 2000, [DIRS 151945] Sections 4.5, 8.2, and 8.3.3; DOE 2002, [DIRS 155943] Section 4.2.9). Surface-based testing of the unsaturated zone included determination of stratigraphic units from borehole logs and air-injection testing, and infiltration rates determined from flux calculations, water-balance models, statistical modeling, and geochemical methods. Surface-based testing of the saturated zone included the C-Wells Complex that measured the flow and transport characteristics of the saturated zone aquifer. These tests are the basis for the filtration of colloids and dispersion models of the fractured rock in the saturated zone.

Surface-based performance confirmation activities include testing to evaluate hydrologic conditions in the unsaturated and saturated zones. Precipitation will be monitored to evaluate and extend the precipitation record at the site and will provide data to be used in stable conjunction with seepage to evaluate performance of the Upper Natural Barrier.

Saturated zone testing includes monitoring groundwater in wells upgradient and downgradient of the repository, and associated laboratory testing of samples to determine groundwater chemistry and radionuclide concentrations. In addition, fault zone hydrologic characteristics; including anisotropy in the saturated zone will be measured. Observation of large magnitude fault displacements after significant seismic events will be conducted. Tracer testing at the Alluvial Test Complex will also be performed. Seismic monitoring will continue to be conducted with both surface-based and underground instrumentation.

3.4.2 Activities in Emplacement Drifts and Mains Prior to Emplacement

During construction of the underground facility, mapping of drift and shaft walls will be conducted. Mapping includes fractures, fault zone characteristics, stratigraphic contacts, and lithophysal content and characteristics of the rock mass. Samples will be collected from the underground facility to determine unsaturated zone chemistry, including chloride mass balance and isotope chemistry through laboratory analysis. Transport and sorption properties in the Topopah Spring Tuff unit are measured by tests in the emplacement drifts. Instrumentation will be provided to measure construction deformation while confirming mechanical properties. Underground activities include seepage and seismic monitoring, visual inspections, and access to boreholes drilled from observation drifts.

3.4.3 Activities in Emplacement Drifts and Mains After Emplacement

Activities that take place in loaded emplacement drifts will include seepage monitoring periodic inspection of drifts (to confirm the ability to retrieve), dust buildup monitoring and monitoring of waste packages. The thermally accelerated drift testing also occurs in loaded emplacement drifts but is more intensive and requires careful thermal management consistent with the test objectives. It is discussed separately in Section 3.4.5. Seals testing may occur in mains and shafts. It is also possible that seal testing could be conducted in comparable rock outside of the repository footprint, depending on the criteria detailed during PC Test Plan development.

3.4.4 Laboratory Testing

Many of the tests require a laboratory analysis component. A few of the tests are laboratory only, including corrosion testing and waste form testing. Activities that include a laboratory component in addition to a field component include precipitation monitoring, saturated zone monitoring, saturated zone fault zone tracer testing, saturated zone alluvium tracer testing, analysis of unsaturated zone water samples, unsaturated zone transport properties tracer testing, analysis of seepage samples, analysis of dust samples, analysis of gas, water and microbes from the thermally accelerated drifts, and corrosion testing of samples obtained from the thermally accelerated drifts.

3.4.5 Thermally Accelerated Drift Test Bed

The goal of thermally accelerated testing is to gain technical insight into the repository postclosure response to heat within the emplacement drifts. Thermal testing began during site characterization, such as the Drift Scale Test, which is currently in the cooling phase. Thermal testing will continue during repository operations with construction of one or two thermally accelerated drifts. A "one-drift" thermally accelerated drift test concept has been evaluated and details can be located within previous revisions of this plan. The one-drift concept may have favorable aspects compared to the two-drift concept, but special handling of the waste packages is a prerequisite. If the special handling requirements of the waste packages cannot be performed, then the two-drift concept, or another alternative concept, will be implemented. This is a new test bed that will be initiated during operations, continuing until closure. As such, for the field-testing, the locations, durations, and design of the test bed configuration are conceptual at this time. Monitoring and testing activities within the test bed will be conducted periodically at a frequency yet to be determined. Other methods and approaches may be employed and will be described in the PC Test Plans for the activities that will be conducted within the thermally accelerated drift test bed prior to waste operations.

A remote means to monitor and collect samples in bulkheaded alcoves is needed. High-temperature and high-radiation environments representative of postemplacement conditions in thermally accelerated drifts will require development of technology with remote monitoring capabilities. Revisions to the performance confirmation program will update this activity description, as appropriate.

Performance confirmation activities in the thermally accelerated drifts will include monitoring in drift conditions, exposing samples of Engineered Barrier System materials to potential corrosion mechanisms in a realistic in situ environment, monitoring of drift degradation, and testing of near-field coupled processes. The activities that are planned to be executed in the thermally accelerated drifts include:

- Seepage monitoring (Section 3.3.1.2)
- Drift inspection (Section 3.3.1.8)
- Thermally accelerated drift near-field monitoring (Section 3.3.1.9)
- Dust buildup monitoring (Section 3.3.1.10)
- Thermally accelerated drift in-drift environment monitoring (Section 3.3.1.11)
- Thermally accelerated drift thermal-mechanical effects monitoring (Section 3.3.2.4)
- Corrosion testing of thermally accelerated drift samples (Section 3.3.4.3).

The discussion that follows identifies potential options and locations for such testing, but these are not all inclusive and other methods and arrangements may be employed. Screening calculations supporting the conceptual test design conclude that two accelerated drifts may be required (see Figure 3-1).

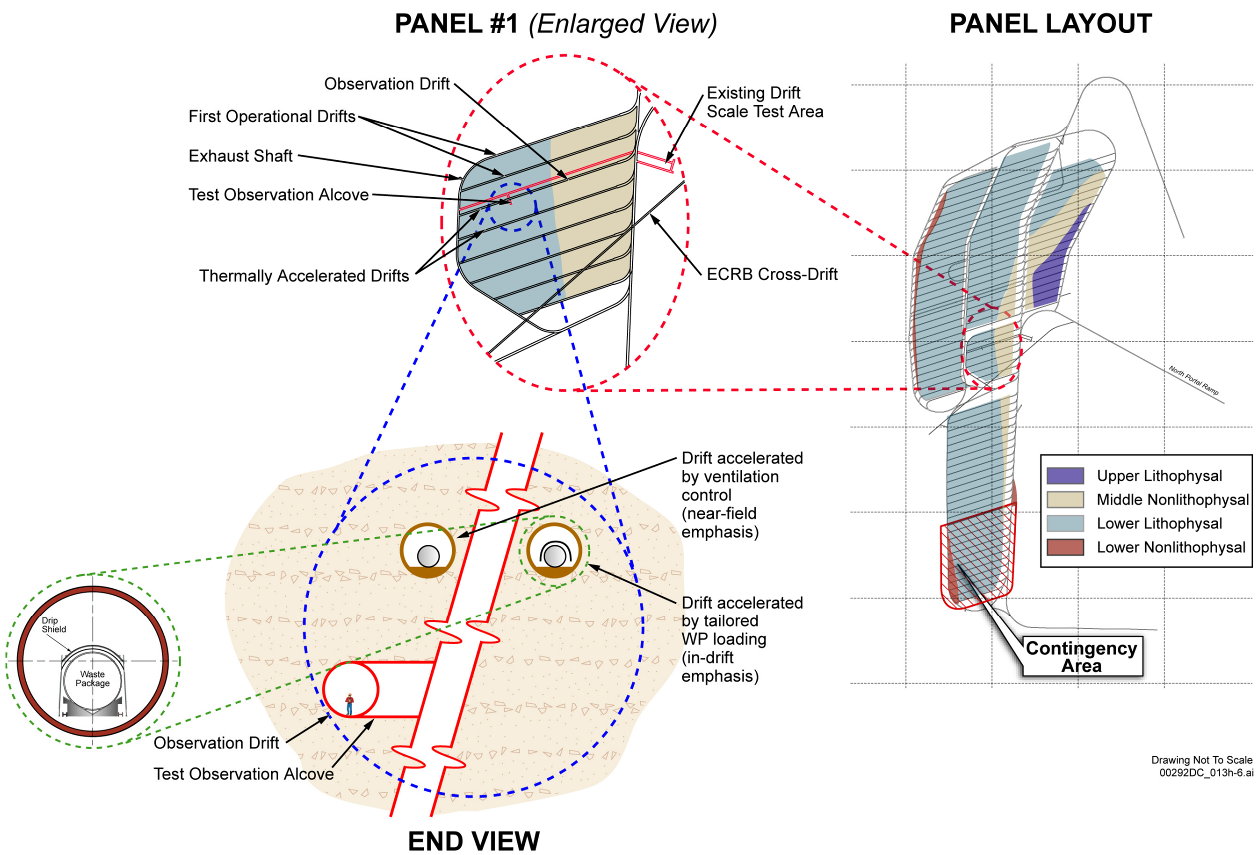
Purpose–The primary purpose is to develop the thermally accelerated drift test that, using normally constructed emplacement drifts, ensures the proper implementation of the activities conducted in the thermally accelerated drifts. The thermally accelerated drifts test approximates two extreme thermal environments (peak and near ambient temperatures). The thermally accelerated drift test develops thermal environments in which representative coupled thermal, hydrologic, mechanical, chemical, microbial, and radiological processes and behaviors can be monitored and observed.

Description (Two Drift Concept)–One accelerated drift will be loaded and configured in the same manner as other emplacement drifts in the repository. That drift would be used to evaluate postclosure maximum temperatures. The testing program will monitor ventilation, reduce it gradually, and allow temperatures to climb into the postclosure range. When high temperature effects are attained after a 10- or 15-year period, the drift ventilation will then be increased to allow the drift to cool below boiling temperatures prior to repository closure. Near-field processes, with minor perturbations due to cooling toward the drift, would be accelerated from about 2,000 years to nominally 100 years; however, the ventilation would overwhelm in-drift hydrologic phenomena such as seepage and condensation. The only significant difference in the test configuration, compared to conditions in the rest of the repository, is in controlling the ventilation and allowing temperatures to rise during the preclosure period.

The other accelerated drift will be used to evaluate in-drift and drift wall subboiling to boiling effects and then later, to evaluate the reversal from boiling to subboiling temperatures. The thermal, hydrological, mechanical and chemical effects must be observed in the absence of ventilation. This drift will require careful thermal management using derated (i.e., less than full) waste packages, waste of a different age (i.e., time withdrawn from a reactor) than the average waste, larger spacing between waste packages than standard in the regular emplacement drifts, or the movement or replacement of waste packages at termination of ventilation. The ventilation in this test will be terminated at an early time, after approximately five to fifteen years. Although the radial extent of thermal perturbation will be limited and peak temperatures will not reach repository postclosure levels, the in-drift and near-field region will experience a thermal cycle that transitions through the boiling range during heating and cooling phases. The temperatures expected in this test are in the range thought to contribute most to coupled process effects. Because in-drift hydrological phenomena will be similar to the postclosure repository, drip shields will be installed in all, or part, of this drift at the time of ventilation termination.

An observation drift will be at a lower elevation than the two heated drifts. Alcoves and boreholes from the observation drift will be used to position instruments in the near-field rock. This will allow instrument maintenance without having to enter the heated drifts. Boreholes drilled from the heated drifts will be few to none.

Instrumentation and baseline measurement completion of the two accelerated drifts will be accomplished during the one or two year period required to emplace waste packages in the drift of the first panel.



NOTE: Not to scale.

Figure 3-1. Conceptual Location of the Thermally Accelerated Drift Test Bed within the Underground Facility

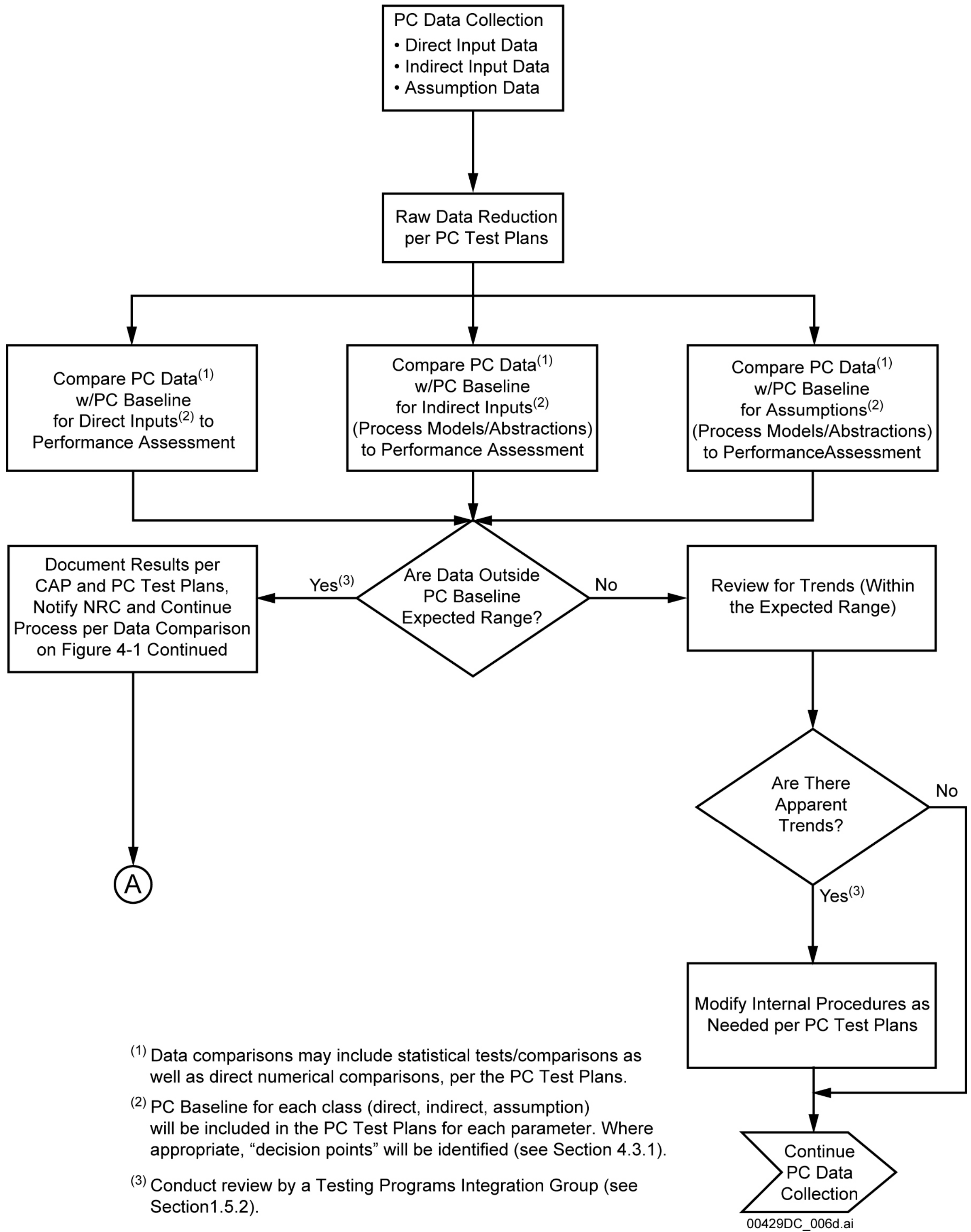
4. DATA MANAGEMENT, ANALYSIS, AND REPORTING

This section describes the approach to the development of the performance confirmation program baseline information (preliminary baseline) and the approaches for the handling of parameter measurements, parameter measurements analysis and evaluation, and the reporting and recommendations (where appropriate) for corrective actions.

The performance confirmation program is an ongoing program directed at collecting information per 10 CFR 63.102(m) ([DIRS 156605]) to "evaluate the adequacy of the assumptions, data, and analyses in the License Application that led to the NRC findings that permitted construction of the repository and subsequent emplacement of the wastes" (NRC 2003 [DIRS 163274]). As described in Section 1.1 and in detail in Section 6, the performance confirmation program began during site characterization when data were collected to describe the site and quantify barrier performance (DOE 1988, [DIRS 100282] Volume VII Section 8.3.5.16). The performance confirmation program will continue until permanent closure of the repository. Data collected in the prelicensing phases of the performance confirmation program are used for evaluation of barrier effectiveness in performance assessments supporting the License Application.

Parameter Monitoring Data–Selected geotechnical and design parameters, including interactions between natural barrier features and engineered barrier SSCs, will be monitored during construction, emplacement, and operation to identify changes in the conditions assumed in the License Application, if any, that may affect compliance with the postclosure performance objectives for individual and groundwater protection, and the preclosure performance objective for preserving the retrievability option. The information collected will be used to confirm that the actual subsurface conditions encountered and changes in these conditions during construction and waste emplacement operations are within limits assumed the License Application Performance Assessments.

Barrier Monitoring Data–The program will also provide information to indicate whether the natural barrier features and engineered barrier SSCs designed or assumed to operate as barriers after permanent closure are functioning as intended and predicted. Figure 4-1 illustrates a generalized management and evaluation process that will be routinely used to evaluate performance confirmation program results. If the information obtained from the performance confirmation program is inconsistent with that presented in the License Application, then the NRC will be informed. The variance will be evaluated and, if the variance is determined to be significant, mitigating actions will be evaluated, including potential design changes. The NRC will be notified.



(1) Data comparisons may include statistical tests/comparisons as well as direct numerical comparisons, per the PC Test Plans.

(2) PC Baseline for each class (direct, indirect, assumption) will be included in the PC Test Plans for each parameter. Where appropriate, “decision points” will be identified (see Section 4.3.1).

(3) Conduct review by a Testing Programs Integration Group (see Section1.5.2).

Figure 4-1. Generalized Flowchart Illustrating Performance Analysis and Trend Detection Process

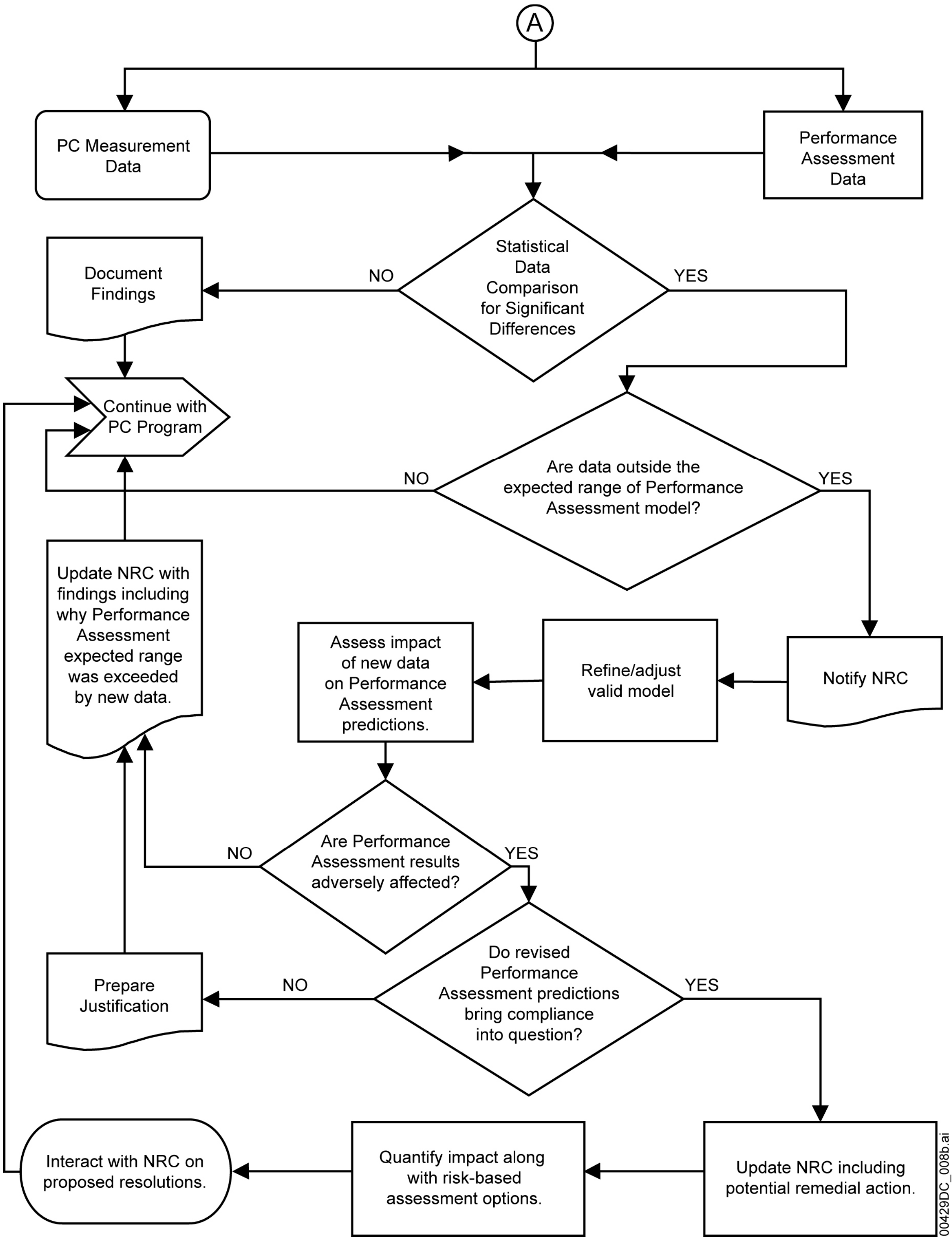


Figure 4-1. Generalized Flowchart Illustrating Performance Analysis and Trend Detection Process (Continued)

Performance Confirmation Activity Flexibility–The performance confirmation program must be flexible with specific details of the program evolving as necessary in response to information obtained from performance confirmation activities as well as from other testing and analysis programs conducted in parallel (see Section 1.5). The performance confirmation program may also need to be revised in response to design changes that affect the nature of the activities conducted or program implementation. The evolution of the performance confirmation program will be iterative, risk-informed, performance-based, based on the evaluation of new information and the identification of changes that will improve effectiveness or efficiency. These changes will be reflected in revisions to the *Performance Confirmation Plan*.

Data Collection Implementation–Testing and data collection details will be defined in PC Test Plans along with appropriate implementation documents as discussed in Section 5. For parameters monitored within the scope of the performance confirmation program, baseline information and acceptable deviations from the baseline information will be identified for each parameter to the extent practicable.

Performance Confirmation Data Evaluation–Evaluation of performance confirmation monitoring or measurement results is influenced by two important factors: (1) the character of the monitored or measured parameter value, and (2) the method used to identify and evaluate changes from baseline conditions that could affect performance of the repository. Sources of baseline condition data are summarized in the current understanding subsections for the activities listed in Section 3.

Evaluation of data is described as a process or approach because the nature of performance confirmation may require long observational periods and may involve monitoring slow, transient development of the responses of the repository to construction, operations, or natural conditions. The discussion of data evaluation is based on the premise that the data gathering process has been validated in accordance with approved procedures confirming instrument function, instrument calibration and raw data collection and reduction. Baseline values for performance confirmation parameters can be discussed in terms of separate points or distributions.

The performance confirmation program is directed at parameters (assumptions, data, analyses) used to evaluate the performance of the natural and engineered barriers, or system performance, as presented in the License Application performance assessments. Confirming the parameters affecting repository barrier or total system performance will demonstrate compliance with the performance objectives for individual protection (10 CFR 63.113(b)) and groundwater protection (10 CFR 63.113(c)), and the preclosure performance objective for retrievability (10 CFR 63.111(e)). As defined in CFR 63.132 (d) measurements and observations must be compared with the original design bases and assumptions. If significant differences exist between measurements and observations and the original design bases and assumptions, the need for modification and significance to repository performance will be reported to the NRC. Thus, this program confirms information used to assess performance as it was evaluated for the License Application.

The method used to evaluate parameter changes from baseline conditions is to compare its value relative to the range used in performance assessments or design considerations. As long as the monitoring results or measurements are not statistically different from the value used, the continuing adequacy of that value to support the demonstration of compliance with the performance objectives is confirmed. If the results are outside the range of values considered in the performance assessment then the use of that value for compliance assessments requires further evaluation.

Data Ranges–Most parameters of interest in performance confirmation are expected to exhibit spatial and temporal variability and will be sampled over the period of performance confirmation and varying interrogation intervals. Mindful of the requisite time for experiment deployment and transient evolution of test conditions, the treatment of data is illustrated here by an example using statistical ranges. After some predefined statistical analysis (e.g., calculated values for the mean, upper bound of the expected value at a particular confidence interval, trend analysis) the reduced data will be compared to a set of predefined limits to determine an appropriate action. The performance confirmation data evaluation is based on two constraints:

- **Expected Range**: portion of parameter baseline used for performance assessment for which no action is required.

- **Condition Limits**: the discrete value(s) or trend(s) outside (upper or lower) the expected range that results in more detailed evaluation and potentially additional sampling, including adversely developing trends as defined in the PC Test Plans.

Figure 4-2 describes the relationship between condition limits and the ranges of acceptable performance requiring no action (the parameter values are within design and model validity bounds) or unacceptable performance requiring action. For those in the distributed monitoring category, some analytically determined cutoff based on performance assessment would be used. For parameters used in performance confirmation models, the expected range will be identified for both the nominal and disruptive case modeled ranges. The expected range is often a design basis or the range from model realizations. Discussion of the expected system and barrier performance is contained in documentation in support of the License Application (BSC 2004 [DIRS 168504]). The expected range developed for performance confirmation purposes will be developed considering (1) allowance for natural or measurement related variability, (2) expectations of the technical measurements (data quality objectives), (3) performance assessment results remain acceptable for values within the limits, and (4) substantial margins are maintained between condition limits and values representing design criteria, or significantly influencing determinations of barrier functionality or compliance with performance objectives.

The condition limits will be developed from a scientific judgment of variance, yet still within a range that provides model results demonstrative of compliance with performance objectives. The condition limit will be the value that activates further evaluation, including probable NRC notification. The condition limits will be defined during the planning phase of a data collection activity based in part on a parameter's importance to performance and a technical evaluation of the data. Condition limits for parameters will be discussed and defined in the PC Test Plan for each monitoring or measurement activity. Each PC Test Plan will define the appropriate sampling, monitoring, testing, or reporting frequency depending on the specific parameter needs. PC Test Plans will set decision rules and responses. These rules and responses comprise an

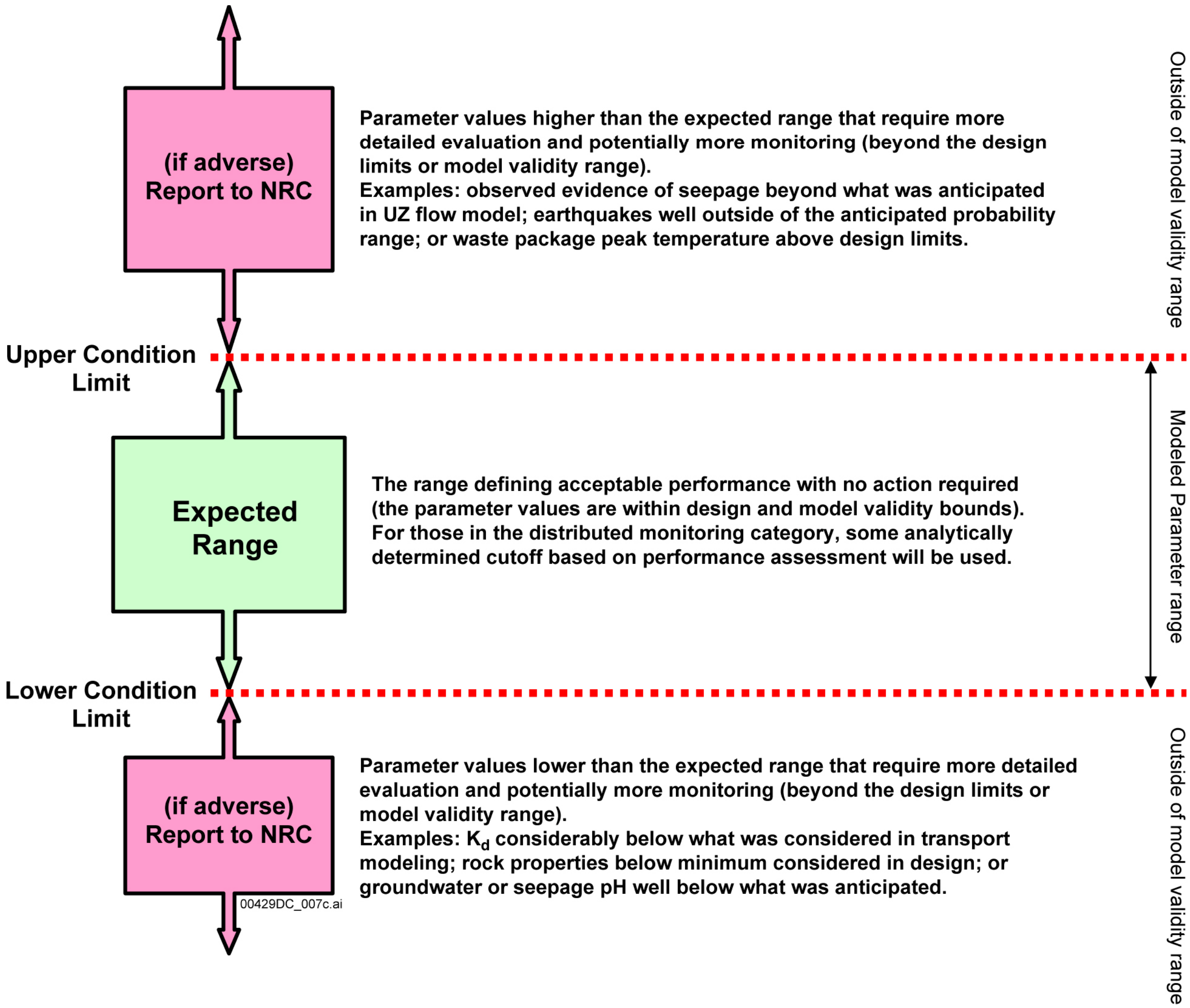


Figure 4-2. Expected Range and Condition Limits

evaluation of conditional statements that specify the following criteria: (1) how the sample data will be compared to the condition limit, (2) which decision will be made as a result of that comparison, and (3) what subsequent action will be taken based on decisions. These criteria essentially derive from test expectations and are predicated on the governing technical difficulties (time, space, accuracy, etc.) embodied in the particular activity or test.

Condition limits are conservative because they may impact repository performance but are set below the point at which environmental damage or barrier degradation is anticipated. For some parameters, exceedance in one direction may be adverse, while it would be advantageous in the other. For other parameters, exceedance in either direction could have potentially adverse impacts on repository performance.

Test Parameters and Test Methods–As previously discussed in Section 1.3.1, an eight-stage approach has been adopted for selection of test parameters and test methods. This section discusses Stage 2, predict performance and establish a baseline; Stage 3, establish bounds and tolerances for key parameters; Stage 7, analyze and evaluate data; and Stage 8, recommends corrective action in the case of variance. Because of the complex and possibly highly nonlinear nature of performance assessment, Stages 3 and 7 are difficult to address in isolation. These steps are discussed together in this section. The initial selection of the performance confirmation parameters (Stage 1) has been completed and is presented in Table 1-1). This initial selection of test parameters and test methods will be reassessed after update of the TSPA-LA.

Baseline Information Development–The next step (Stage 2) in the implementation of the performance confirmation process is to define the baseline using the performance assessments from the License Application. The information is then used to define the details of each performance confirmation experimental investigation. PC Test Plans will be developed for each activity or group of activities. Baseline information (i.e., the ranges of existing data and model validity ranges) for parameters will be presented in those plans. Test completion criteria and variance criteria will be developed and described.

Data and findings from the performance confirmation program will be analyzed and reduced as necessary and compared to the corresponding baseline information. The initial comparison will be based on statistical tests of the raw data to determine if the new data might not be from the same population as the baseline information. If a statistically significant difference exists between the parameter measurements and the baseline information, then an evaluation of the impact on performance will be made. Performance assessment and barrier analyses will be used to develop applicable condition limits and descriptions of expected trends for those parameters that impact performance (the following Sections 4.2 and 4.3 provide a more detailed discussion). For activities or parameters intended to confirm that design specifications have been met, comparison with design bases specifications will be performed.

4.1 PERFORMANCE BASELINE INFORMATION

4.1.1 Baseline

To assess the impact of newly acquired data and information on the performance evaluations used in the licensing review, a performance confirmation baseline will be identified with pointers to data and assumptions used. For the first performance confirmation iteration, as discussed in this plan, the initial baseline information will be derived from information contained in calculations, process model analysis reports, and TSPA-LA. Performance assessment model input parameters (excluding simulation settings and TSPA system parameters which are outside the performance confirmation program) are found in the TSPA Input Database (which will be provided as upcoming in TSPA-LA model document (BSC 2004 [DIRS 168504])) along with links to the source documentation. The additional (upstream) parameter data used as inputs to analyses and models to generate the direct inputs to the License Application will be added to the baseline to facilitate evaluation of the specific measured parameters. Descriptions of what constitutes the baseline information for each parameter will be documented in the PC Test Plans developed for specific parameters or groups of parameters. For geotechnical and design parameters, the baseline information is determined using analytical or statistical methods as reported in the source documentation.

4.1.2 Data Categories

Within the performance confirmation program, there are three categories of data that may be provided by each activity. The first consists of data values and distributions required by performance assessment, such as geophysical data of densities, distribution coefficients, porosity, and thermal capacity. These data are analyzed in reports to generate input data or distributions of such data for use by performance. Some of these analyses are relatively straightforward such as deriving a distribution for rock density in a particular unit. Others may be complex such as the generation of the saturated zone breakthrough curves as a function of physical parameters such as sorption coefficients, colloid concentration, colloid retardation factor, diffusion coefficient, effective porosity, and horizontal anisotropy.

The second category is generated by tests producing results that are used to evaluate the results from individual process models. These are the models used to derive parameters (i.e., model abstractions) used in performance assessment. Parametric studies (temperature, pH, salinity) for the laboratory and in situ corrosion test data as well as the time evolution data (rock temperature and moisture content) captured in the thermally accelerated drift fall into this category.

The third category consists of data associated with processes not numerically modeled in performance assessment but which are included by assumption. Examples of such assumptions are the focusing of infiltration seepage onto a limited number of waste packages and the effectiveness of borehole and shaft seals in preventing increase in predicted seepage into the emplacement drifts.

4.1.3 Performance Confirmation Activities and Parameters

Table 3-2 provides a crosswalk between parameters and the proposed activities. For each activity the table gives a brief summary of the parameter(s) to be measured along with an objective of the activity. The next column of the table defines the purpose of the activity in terms of how the data are to be used in the categories mentioned above. The last column of the table lists a reference to Section 3 where preliminary baseline information sources are described for each activity.

Baseline Information Locations–The direct input data (parameter values including variability and uncertainty distributions) used in TSPA are controlled and readily available. The details of models and abstractions used in performance assessment exist in supporting analysis and model reports where model specific parameters are defined. These supporting modeling and analysis documents will provide parametric ranges over which the individual models are valid along with other model or data limitations that could cause parameter validity to be questioned. Performance confirmation items for which performance assessment made assumptions will be identified and included in the baseline information.

Baseline Information Updates–*Total System Performance Assessment-License Application Methods and Approach* (BSC 2003 [DIRS 166296]) lists a large number of parameters that were expected to be used by TSPA and about 300 of these parameters are distributions rather than single values. Where employed, the distributions reflect the uncertainty and/or variability in the parameter.

The results of sensitivity and uncertainty studies and the various process models and abstractions will be used to identify process models and data sets that have a potential to significantly affect the postclosure performance assessment predictions if they are changed. These studies will provide insight into the analysis required to determining what margin is available for changes in the input data before performance assessment predictions are significantly affected.

4.2 PERFORMANCE ANALYSIS

4.2.1 Impact on Postclosure Performance Assessments

Direct Input Data–The process of determining whether new data or information has an impact on reported postclosure performance assessments depends on the type of performance confirmation activity. Data that are used directly in the performance assessment models are the most readily assessed, because they are amenable to direct comparisons.

Indirect Input Data–The second group of activities is comprised of those experiments conducted in the laboratory where data are taken as a function of environmental parameters (e.g., pH, Eh, temperature) or conducted as part of the thermally accelerated drift test. These measured data will require additional processing before a meaningful comparison can be made to the baseline information or supporting process model.

Assumptions–This category of measurements includes activities that provide data on an aspect of the repository for which assumptions were made in developing the performance assessment models. As examples, the hydraulic and transport properties of alluvium are a broad range based on similar materials found elsewhere as well as laboratory batch and column tests. The hypothesis is that alluvium, under normal circumstances can enhance performance. Because of the uncertainty in the length of the flow path in alluvium and the true range of hydraulic and transport properties of the alluvium in the vicinity of Yucca Mountain, the program uses a conservative range to simulate these conditions, which leads to an increase in uncertainly in these parameters. The confirmatory testing to be done in the alluvium is needed because the saturated zone flow model is sensitive to hydraulic and transport properties. Since there are few in situ measurements to date, the results will be used to evaluate if the properties at this specific presumed representative location are within the bounds used in subsystem performance.

Data Impact Analysis–When repository construction begins, performance confirmation will, on a continuing basis, compare the actual preemplacement subsurface conditions with those used in the performance assessment and in the design assumptions. Differences will be assessed for degree of impact on the License Application performance assessment. Findings will be documented and significant adverse trends will be reported as described in Section 4.3. The comparison process will continue after the start of waste emplacement, when thermal, mechanical, and chemical measurements will be initiated. This phase of performance confirmation measurements will continue until a license amendment to close is granted. The following sections provide further discussions on the analysis process.

4.2.2 Addressing Unexpected Conditions

Condition Reporting–The performance confirmation program is designed to detect parameters that deviate from an expected range of values. Predicting long-term performance for the repository at Yucca Mountain is a complex project, so that some deviations from expectations will probably occur. A logical pathway to document, track, and manage deviations significant to performance evaluations starts with recording the condition in the Corrective Action Program per AP-16.1Q, *Condition Reporting and Resolution* ([DIRS 168504]) followed by evaluations detailed in PC Test Plans.

Initial internal reporting of conditions will be done in the Corrective Action Program system. PC Test Plans will describe, for each parameter, what constitutes an observation (the representative value at a particular period), what are predicted acceptable values (those that would not be expected to cause performance to change), what are the expected ranges, expected distributions, condition limits, and identification of potentially adverse trends.

Through routine reporting, NRC would be kept current on progress of performance confirmation activities and their evaluations. The maturation of the collection and evaluation of data will be systematic. A protocol of standard reporting format and interval will be established with the NRC. Thus, the performance confirmation program will be subject to formal reporting in advance of discovery of conditions that differ from those assumed in the License Application. The reporting protocol would call attention to situations such as values outside of the condition limits. Along with NRC notification and evaluation(s) of the cause of the exceedance, an assessment of the potential significance of the deviation and determination of possible corrective actions will be conducted.

For parameters not used in performance assessment models, comparisons with design bases, assumptions, or qualitative barrier capability assessments may require subject matter experts (see performance confirmation integration group discussion in Section 1.5.2) to set the expected range and condition limits. In cases where the evaluation process requires sampling over time, it is possible to observe the time evolution of estimated parameter values and associated uncertainty bands. The time series of reduced data can be analyzed to determine whether there is evidence of a trend that, if it were to continue, would eventually challenge assumptions supporting the License Application and/or adversely impact repository operations. If such a trend is identified, action should be initiated to evaluate possible consequences.

Influence of Data Accuracy on Condition Reporting–Parameters to be monitored under performance confirmation will require varying degrees of accuracy and precision to support decision-making. The appropriate metric should be whether significant deviations important to evaluating assumptions used in the licensing basis have been detected. Requiring unnecessary accuracy or precision or evaluating bias within expected ranges may be misleading regarding the importance of the parameter. PC Test Plans will provide the rationale for how each parameter will be treated, and when conditions are outside of expectations and need to be reported in the Corrective Action Program system.

An example would be where the expected range is not exceeded, but a potentially adverse trend is identified. In this example, the action would be to analyze statistically significant adverse trends to determine if they represent conditions that require a change in operations or a corrective action prior to closure. The approach is intended to facilitate structured, risk-informed, performance-based decisions and actions that are commensurate with the performance significance (possible impact on performance at some future time). The Project will continue to refine its process as experience is gained with the performance confirmation and operations programs and improved performance and risk analysis tools become available.

4.2.3 Data Reduction and Data Categories

For tests where the parameter measured is a direct input (1st category) to the performance assessment after statistical analysis, the basic data will be reported along with a variability and uncertainty assessment. Data that are not used directly (2nd category) in the performance assessment, but are used to generate performance assessment inputs, will need a more detailed analysis. Laboratory corrosion testing is one example where corrosion rates are measured as a function of several fixed parameters (e.g., temperature, pH, salinity, Eh). For use in the performance assessment predictions, these data must be reduced to a multidimensional representation (e.g., a response surface or other abstraction). Another example is that of drift scale corrosion testing in which the multiple parameters evolve over time in accordance with local conditions driven by the applied thermal loading. In the former case, the monitored data must be translated into a usable abstraction for use in the performance assessment. In the latter case, the corrosion process model must be exercised with the baseline information for comparison with the experimental results. Both analyses must assess the variability and uncertainty of the data and propagate the uncertainty to the desired input used by performance assessment. For data included by assumption (3rd category) these assumptions may be reviewed in conjunction with the other data reviews discussed above.

4.2.4 Comparisons of Parameter Measurements with the Performance Assessment Prediction Baseline Information

Preliminary Analysis–In general, the analysis process for each data set involves two steps. In cases where data are being gathered incrementally over varying time steps for a long total period, the following two-step process will be executed as new data becomes available. The first step will be to determine whether there is statistically significant reason (to a defined confidence level) to regard the new data as being sampled from a different parent distribution (or statistical population) than from those in the baseline information. This step also evaluates the representativeness of the new data. In some cases, cyclical behavior may be expected. In those cases, short datasets may only represent a partial subset of the parameter population being evaluated and could lead to a false acceptance of the null hypothesis when none actually exists in a longer record. If the first step indicates a reason to believe that the parameter measurements differ from the performance assessment baseline information, then the second step is to evaluate the performance predictions changes from those made with the baseline information.

Detailed Analysis Techniques–The implementation details of this process depend on three categories of data collection: in the performance confirmation program (direct input data), data comparable to performance assessment results (indirect data), and data that quantify processes not modeled in the TSPA (assumptions). Activities may include preliminary data analysis, statistical, and judgment informed evaluations. Some of the preliminary data analysis tasks include reducing false precision from raw data measurements, combining or separating old and new datasets, testing for outliers, evaluating extreme data values, summarizing and graphical presentation and distribution plotting.

Routine statistical activities that may apply to specific parameters include standard statistics, goodness of fit tests, identifying geospatial and temporal trends, evaluating stoichiometric (geochemical) correlations and other approaches appropriate to geospatial data. For better-understood and less uncertain parameters, it may be appropriate to apply control plot methods. Judgment-informed evaluations might include evaluations of error, accuracy, precision, and complex models. Treatment of these three categories is discussed below.

4.2.4.1 Direct Input Data

Data that are generated to evaluate equivalent data in the performance assessment baseline will directly follow the two-step process previously discussed. A statistical test will be conducted to determine whether or not the new data and the data used in the performance assessment come from the same distribution (1st case). The statistical tests will be structured so as to reduce to acceptable levels the chance of claiming the two data sets are the same, when in reality they are different.

If the statistical test indicates that the new data are from a different distribution (2nd case) than assumed in the performance assessment baseline information, then further investigations will be needed to quantify the effect of the new data on performance assessment predictions. New significantly different data for a particular parameter may cause the performance assessment predictions to be reduced or increased. The former case (1st case) data from the same distribution) could result if the parameter measurements more accurately define an input parameter's range such that extreme values of the parameter are no longer sampled in the stochastic performance assessment. An example of the latter (2nd case) is when the new data distribution provides parametric values that fall outside the region of validity of the process model developed for performance assessment. If the analysis of the parameter measurements is confirmed, then the impact evaluation will require a new performance assessment evaluation with an improved process model to accommodate the new data distribution, and could potentially result in predicted performance outside the regulatory limits.

For parameters that have values within the range of validity of the process model, an estimate of the distribution change impact in input data can be obtained from the TSPA-LA performance assessment sensitivity studies. These studies will be used to identify the change in performance assessment results as a function of input parameter value changes. Because of the complex interrelationships between performance assessment processes, the statistical noise from the simultaneous sampling of other input parameters may necessitate performing a sensitivity study over partial ranges of the parameter total range. This process should provide a first estimate of the new data impact. If this analysis provides significant doubt on the impact, then the corresponding performance assessment model should be run with the new data distribution. The rerun should have the same random number seed for starting the stochastic computations, and should generate the same sets of sampled parameters in order to minimize sampling variations between the two runs. The outcome of this exercise should be a recommended action reflecting the anticipated magnitude of the change in performance assessment predictions.

4.2.4.2 Indirect Data (Comparisons with Model Predictions)

Test Classes–Those tests that monitor parameters as they evolve in the thermally accelerated drift test, and those that measure parameters as a function of multiple independent variables require a more complex analytic approach. Laboratory tests are to be conducted to better quantify the influence of environmental variables on parameters required for the performance assessment. These tests are generally used to support a particular process model. Those tests to be conducted in thermally accelerated drifts are conducted in an environment that is representative of those anticipated in the repository, but do not provide the test operator control over the evolution of the environmental parameters. With many parameters varying over time, it is difficult to quantify the influence of each parameter on the process being studied. However, the two classes of test provide data that can be used to evaluate the performance of one or more process models and quantify model uncertainty in performance assessment predictions using the baseline.

Laboratory Tests–For the laboratory tests, the starting point for the initial new data impact evaluation is the documentation of the pretest predictions and the existing database used for TSPA-LA. Statistical tests will be performed to determine whether there are significant differences between prediction and observation. If there is justifiable reason to believe the process model is not an adequate representation of reality, then the process model may need to be reviewed.

Thermally Accelerated Drift Tests–Tests in the thermally accelerated drifts provide a more complete set of measurements on the time evolution of many temperature (or temperature history) dependant parameters. The thermal loading and measured material properties will allow results from several process models to be evaluated. Again, comparison of predictions for in situ measurements should provide an ongoing indication of whether the process models implemented in the performance assessment could be assessed as functioning correctly. If there is an indication that a particular process model is making invalid predictions that would lead to an increase in the predicted annual dose, the process model may need to be reviewed to decide what path forward is warranted.

4.2.4.3 Comparisons with Model Assumptions

As examples of evaluating assumptions, the hydraulic and transport properties of alluvium are a broad range based on similar materials found at other locations as well as laboratory batch and column tests. The hypothesis is that alluvium, under normal circumstances can enhance performance. Because of the uncertainty in the length of the flow path in alluvium and the true range of hydraulic and transport properties of the alluvium in the vicinity of Yucca Mountain, an assumed range is used to simulate these conditions. This leads to increased uncertainly in these parameters. The testing is done in the alluvium because the saturated zone flow model is sensitive to hydraulic and transport properties, but since there are few in situ measurements to date, a wide range(s) has been used in evaluating subsystem performance. Results are expected to confirm that the properties at this specific presumed representative location lie within the expected range used in models.

Borehole and shaft closure is another example. The TSPA does not model the effect of these openings. Rather, the TSPA makes the implicit assumption that these openings can be effectively sealed such that there is no degradation in properties expected from that of the pristine rock. If testing and modeling reveals a significant performance difference (rate of water ingress to the Engineered Barrier System) between the seals and the parent rock, then the impact of these differences on performance assessment predictions may need to be evaluated after the test design and implementation methods are scrutinized. Alternatively, the seals could be redesigned and retested.

4.2.5 Iterative Performance Evaluation

The performance confirmation program has many independent activities running concurrently over many years. As time evolves, there will be a stream of new data and information becoming available that will continuously improve the knowledge of parameters, assumptions, and process models. As the overall system model, as well as each model for the individual barriers, is dependent in a complex manner upon multiple inputs, each subject to variability and uncertainty, a dynamic approach to determining performance confirmation sensitivities has to be employed. With some parameters better defined than others, the sensitivity of predictions to changes in another parameter evolves with time. Periodically it will be necessary to reevaluate the baseline predictions and recalculate the expected range that defines acceptable performance. The DOE also expects to review periodically the need to exercise the whole TSPA model to evaluate the cumulative effects of new information. Studies will be undertaken to provide a metric for when this renormalization of prediction is required.

4.3 TREND DETECTION, ANALYSIS, AND REPORTING

The following sections provide a preliminary discussion of performance confirmation program actions for: identifying data and performance trends; analyses required of such identified trends; the proposed two tier reporting approach; and the potential corrective actions for consideration.

4.3.1 Notification of Conditions

Condition Recording and Reporting–A logical pathway to determine whether deviations are significant to performance starts with recording the condition in the Corrective Action Program as described in AP-16.1Q ([DIRS 168504]) followed by evaluations detailed in PC Test Plans as described in Section 4.2.2. Figures 4-1 and 4-2 present simplified conceptual flowcharts of the processes.

Many of the conditions refer to construction or operational programs. Recording and reporting under those programs is covered by descriptions of those programs. DOE will be sensitive to results and reports from construction, operation and other testing programs and evaluate the impact of those results and condition reports on the performance confirmation program (see Section 4.3.2).

Use of Other DOE Program Methods–Although DOE Environmental Management Programs focus on remediation of legacy sites, some of the monitoring technologies and analytical tools employed by those programs may be appropriate to performance confirmation activities at Yucca Mountain. Examples of documents that could be evaluated for appropriate analogous methodologies may include: *Requirements-Based Surveillance and Maintenance Review Guide* (DOE 1997 [DIRS 170250]), *EM Corporate Data Collection Guidance for the Interim Data Management System (IDMS) and the Analysis and Visualization System (AVS)* (DOE 1999 [DIRS 170252]), *Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites* (DOE 1999 [DIRS 170253]), *Technical Guidance for the Long-Term Monitoring of Natural Attenuation Remedies at Department of Energy Sites* (DOE 1999 [DIRS 170254]), and *Guidance for Optimizing Ground Water Response Actions at Department of Energy Sites* (DOE 2002 [DIRS 170255]).

Use of Industry Methods–For those parameters that have estimated normal distributions (or transformed mathematically to normal), industry standards such as ASTM D 6250 2003, *Standard Practice for Derivation of Decision Point and Confidence Limit for Statistical Testing of Mean Concentration in Waste Management Decisions* ([DIRS 170142]) and statistical methods appropriate to specific media such as: *Statistical Methods for Groundwater Monitoring* (Gibbons 1994 [DIRS 170143]) may be an example of methodologies that apply. In the American Society for Testing and Materials method, a direct comparison of the sample mean (using multiple observations to develop a representative mean) is done against the decision point. A decision point (or condition limit) in the context of performance confirmation is the numerical value that causes a decision-maker to choose one of the alternative actions (e.g., conclusion of compliance or noncompliance). The decision point (or condition limit) is defined during the planning phase of a data collection activity (in this case based on that parameter's importance to performance), it is not calculated from the sampling data. Condition limits for parameters will be identified in the PC Test Plan for that activity.

NRC Notification–The NRC will be notified promptly whenever new data are found that results that significantly differ from the expected range in a direction that would indicate possible adverse impact to annual dose or a trend in data are found that, through time, could develop into a condition that is significantly different than the established performance predictions or the documented design basis. The data evaluation report will provide details to the NRC about the comparison of performance confirmation test data with the data used in the performance assessment predictions.

4.3.2 Evaluation of Conditions

Evaluation Techniques–As previously discussed, evaluation or sensitivity analyses will be conducted for observed conditions using the appropriate model (i.e., statistical, process or total system) to determine whether there is a significant impact on the repository performance with respect to regulatory limits.

If a condition limit is reached, the predetermined decision rule will be applied. Figure 4-1 provides an example flow chart of the evaluation process to determine what actions are required. In the case of adverse variances or deviations, DOE will notify NRC. In both adverse and unexpected but potentially favorable conditions, a condition report is entered into the Corrective Action Program system and followed with a consequence assessment.

Some changes in parameter distributions from performance confirmation activities may result in improvements in predicted performance. The magnitude of the favorable impacts will then be used to determine the type of corrective action required. Based on condition limits, after a favorable condition has been evaluated, details and results of this evaluation will also be reported to the NRC (as a follow-up to initial notification).

4.3.3 Evaluation of Trends

Trend Definition–The first step in determining if a statistically significant trend exists is to test the hypothesis of there not being a trend (i.e., there is no reason to believe the new data differ from the previous data). If this hypothesis is rejected then the next step is to fit a trend line model to the set of indicator data and assess the goodness of the fit. Deciding which model is the best to fit can be accomplished by using some common regression techniques. The regression model that yields the best fit is selected as the trend line model for the data set. It should be noted that this is the only step required to assess whether statistically significant trends exist in parameters, since the slope of the trend line determines whether the statistically fit trend line is adverse.

Trend Sensitivity–In some cases, especially with parameters that have measurement uncertainty and show very little incremental change, but are very important to demonstrate performance, a trend line may not be a sensitive enough tool to recognize changes in the most recent data. Stated differently, would a single point that is an outlier constitute a trend? The exact answer to this question would be determined by a combination of statistical testing and qualitative analysis, and the answer would likely differ for each of the different parameters. The statistical methodologies selected to evaluate each parameter or set of parameters should be capable of raising a warning flag based on the degree of deviation from the trend line or other objective model. If a warning flag is raised, additional emphasis will focus attention on the particular parameter.

Trend Identification–Prediction limits provide a reasonable way to assign condition limits and decide if a future abrupt increase in a parameter is of sufficient magnitude to conclude that it is statistically significant. In other words, if the historical data with regression methods are modeled, and if future behavior is consistent with past behavior, then it is possible to compute an upper limit that will contain a future value of the dependent variable with a specified degree of confidence (i.e., 95 percent). If the following period’s observed result exceeds this limit, then one might conclude that a statistically significant adverse change has occurred.

Trend Evaluation–Once a potential adverse trend is identified, an initial analysis of information readily available in the baseline would be used to determine whether the trend is unduly influenced by a small number of outliers and to identify contributing factors. If the trend is the result of outliers, then it will not be considered a trend requiring corrective actions, but the testing and measurement procedure will be evaluated in relation to the parameter’s importance to confirmation of performance to determine if another method or system may be better suited to monitoring. If the outliers are caused by cyclic components, a modification of sampling frequency may be recommended. If no outliers are identified, broader investigations will be conducted to assess whether a larger set of unmonitored or poorly constrained parameters may be contributing to the trend, and to assess contributing factors and causes.

Evaluation of Trend Significance–Once this information is reviewed, the Project will assess the performance significance of the underlying issues. Trends in individual parameters must be considered in the larger context of their overall risk significance. For example, a hypothetical systematic increase in the estimate of the drip shield corrosion rate distribution from a mean value of Y to Z over several years may be a statistically significant trend in an adverse direction. However, it may not represent a significant increase in overall risk since the contribution of that parameter is relatively low, and it is possible that overall risk may actually have declined if there were reductions in the frequency of more risk significant initiating events or the reliability and availability of performance systems had improved.

4.3.4 Potential Corrective Actions

The recommended corrective action for a given set of data will be based on a combination of the potential adverse effects and the probability of those conditions actually being present (i.e., risk based). Condition limits for each parameter will be developed from barrier capability analyses or performance assessment sensitivity evaluations, and identified in the PC Test Plans. If the new data indicate that there is a small probability that the mean performance assessment predictions would increase by even a minimal amount, then this finding will be reported with a recommendation that no action be taken. However, if a new data set is developed and the resultant input data change could cause a significant change in performance assessment response (that is, exceeds a predetermined condition limit or shows an unexpected trend that may cause a condition limit to be exceeded at some future time), then the original data will be subject to a detailed review, report, and possible action.

INTENTIONALLY LEFT BLANK

5. TEST PLANNING AND IMPLEMENTATION

Whereas the previous section described the approach to the development and handling of the performance confirmation program baseline information, this section will describe how the program of activities will be implemented in the laboratory and the field through test planning and implementing documents. New implementing procedures will be developed to cover performance confirmation identification and notification processes. This section describes the process by which the PC Test Plans will be developed and their content. It acknowledges that a process, based on Figure 4-1 and the discussion in Section 1.6, will be required, developed, and implemented through the PC Test Plans for notification protocol if variances from the parameter values are outside expected ranges. The section also provides the plans for management structure and interfaces for field implementation of the activities. A table is provided to summarize the list of activities conducted or initiated during site characterization, that are comparable to identified performance confirmation activities, with a reference to governing technical work plans, scientific investigation test plans, and field work packages, and a brief description of the performance confirmation work conducted during site characterization. Further details regarding the schedule and timing of individual activities was provided in the description of the activities in Section 3 and provided in Section 6 in a broader context.

5.1 GENERAL

The processes involved in planning and implementing performance confirmation testing activities, through PC Test Plans and the underlying processes, in compliance with the *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171386]) and *Augmented Quality Assurance Program (AQAP)* (DOE 2004 [DIRS 171341]), are presented below.

Performance confirmation testing and monitoring activities will be conducted in accordance with appropriate technical, safety, environmental, and quality procedures.

The planning process for performance confirmation activities will be adapted to include information directly applicable to performance confirmation, for example, baseline information, variance criteria, and the process followed if the measurements are outside the preestablished expectations, including the NRC notification criteria. In addition, emphasis will be given to instrumentation selection, maintenance, reliability, and calibration when considering that many of these tests will be in locations not easily accessible or underway for long periods of times. As with all testing and monitoring activities, each performance confirmation activity is evaluated to assess relevance to: worker safety; waste isolation impacts due to test construction, performance confirmation activities or both; potential interactions between independent activities; and potential interactions between repository construction activities and performance confirmation activities.

To implement the performance confirmation testing program, a single organization will be designated as the lead. This organization will be responsible for the maintenance of the *Performance Confirmation Plan*, development of the PC Test Plans, interfacing with TSPA and process model teams for establishing limits and ranges on parameters, interfacing with the test implementation and field test coordination organization to ensure the monitoring and testing efforts are accomplished, and for developing notification and general reporting processes. Management will:

- Select personnel with appropriate qualifications to conduct and manage performance confirmation activities
- Ensure that personnel have completed necessary indoctrination and training in accordance with AP-2.1Q, *Personnel Training and Qualifications* ([DIRS 170114])
- Ensure that personnel conduct the activities in accordance with the procedures necessary to properly control their work. When sufficient procedures do not exist for controlling the work, management will ensure that new procedures or revisions to existing procedures are prepared and approved.

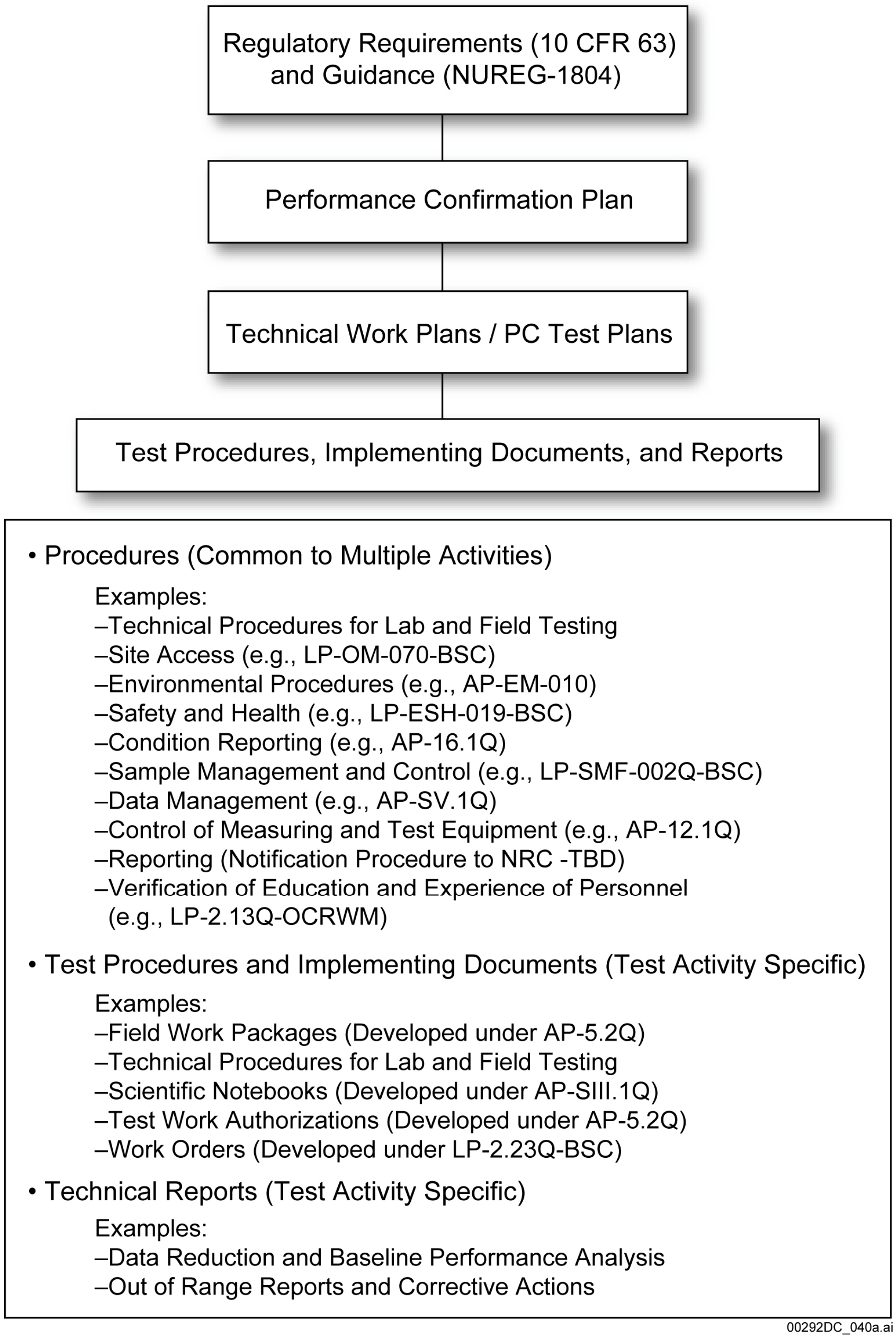
Resources necessary to implement the performance confirmation program will be identified and captured in the Multiyear Planning system.

5.2 IMPLEMENTATION OF PERFORMANCE CONFIRMATION ACTIVITIES

The process for performing performance confirmation activities requires both planning and implementing documents and reports on monitoring results. This process will be similar to the one used for site characterization utilizing a multi-tier planning process, implemented by technical procedures and other work control documents as described in more detail in Sections 5.2.2 and 5.2.3. Figure 5-1 shows the hierarchy of planning and procedural documents relevant to implementation of performance confirmation testing and examples of the general procedures required for testing programs (e.g., environmental, safety and health; sampling; and personnel qualifications).

5.2.1 Experiment Design for Performance Confirmation

The performance confirmation program focuses attention on those areas where model uncertainties or assumptions could have a significant impact on performance assessment predictions. The data and assumptions used in the License Application's performance predictions are the initial basis of performance confirmation baseline information to translate barrier capability or performance assessment input parameters into performance confirmation measurable parameters. The input and intermediate vectors (i.e., calculated internally in the performance assessment model) along with attendant sensitivity studies allow evaluation of the relative importance of the uncertainties in parameter values, ranges, and distributions. Thus, modification of the *Performance Confirmation Plan* will refine the baseline and will be performed after the License Application is submitted. It will be based on the performance assessment computer simulations and the documented assumptions to ensure that the most recent model understanding and implementations are captured.



Sources: 10 CFR Part 63 [DIRS 156605], YMRP NUREG-1804 [DIRS 163274], LP-OM-070-BSC [DIRS 170704], AP-EM-010 [DIRS 167728], LP-ESH-019-BSC [DIRS 170072], AP-16.1Q [DIRS 168504], LP-SMF-002Q-BSC [DIRS 172199], AP-SV-1Q [DIRS 168938], AP-12.1Q [DIRS 170701], LP-2.13Q-OCRWM [DIRS 170114], AP-5.2Q [DIRS 168667], AP-SIII.1Q [DIRS 165688], LP-2.23Q-BSC [DIRS 170703]

Figure 5-1. Planning and Procedural Document Hierarchy Relevant to Performance Confirmation Testing Implementation

The experiment design and analysis teams for the performance confirmation activities will be assembled from subject matter experts of the required disciplines. The subject matter experts will review each of the proposed activities (as previously given in Section 3) in the context of the performance assessment results and sensitivity studies to identify those parameter value ranges and distributions important to performance confirmation.

The PC Test Plans will describe the monitoring, testing, and collection of data, including the methods for analyzing and evaluating the information. They will also establish bounds and tolerances for parameters, test completion criteria, and develop criteria for constructing and installing the performance confirmation program activities. Test plans will contain variance conditions, required actions, and completion times for reacting to measurements or observations that are at variance with expectations.

Individual parameters require different sampling and instrumentation methods depending on how that parameter is expected to react to change. If temporal impacts from construction, operations, or natural variations are significant, then parameters may be monitored as a time series. The magnitude of the variation may not be enough during the period of performance confirmation to impact performance, but a trend extended over a very long period and under different climate and thermal scenarios may. The design of the testing evaluates how trends, in such cases, will be detected and analyzed. A sequence of observations is influenced by three separate components: (1) a trend or long-term component, (2) cyclical or oscillation functions about the trend, and (3) a random or irregular component. The PC Test Plans should address how each of these potential components will be handled and how sensitive performance would be to unexpected results in the components.

Activities that will be used, as appropriate, to evaluate parameters (observations, sets of observations, or distributions) include preliminary data analysis, statistical analysis, process models, performance assessment subsystem models, and judgment informed evaluations (see Section 4.2). In addition, as appropriate to a specific set of parameters, industry standard methods, such as ASTM D 6250, 2003, *Standard Practice for Derivation of Decision Point and Confidence Limit for Statistical Testing of Mean Concentration in Waste Management Decisions* ([DIRS 170142]) may be used to set decision points (similar to condition limits in this plan), decision rules, and the confidence limits. Decision rules and decision points may also apply to observed trends. This will not be required for all cases, but only for activities requiring some additional criteria and decision methods. For geostatistical data and non-normal distributions (or potentially distribution-free variables), other tests that do not depend on normal or transformed normal (e.g., log-normal) distributions may apply. Definition of evaluations of this type belong in the PC Test Plan as it is very parameter specific especially depending on what range of values may be considered as impacting annual dose or design. The PC Test Plans will specify how the monitoring, testing and experimental methods will be suitable for individual parameters in terms of time, space, resolution, and technique. Instrument reliability and replacement requirements are considered in the design of the testing program. The analyses on which these evaluations are based will be documented in accordance with the quality assurance process.

As an example of the kind of statistical testing that may apply to some normally distributed parameter measurements, based on ASTM 6250 [DIRS 170142] above, the PC Test Plan must state the problem and a decision rule. A decision rule is a set of directions in the form of a conditional statement that specify the following: (1) how the sample data will be compared to the decision point, (2) which decision will be made as a result of that comparison, and (3) what subsequent action will be taken based on decisions. A decision point can then be established. A decision point, in the context of performance confirmation, is the numerical value or trend that causes a decision-maker to choose predefined alternative actions. The decision point is defined during the planning phase of a data collection activity (in this case based on that parameters importance to performance); it is not calculated from the sampling data.

Activities that are considered in performance confirmation and focus on parameters that are sensitive to experimental boundary conditions and predictions based on performance assessment inputs will be included in the detailed PC Test Plan. The predictions will be part of the experiment optimization process. The performance assessment models will be used, as appropriate, to make pretest predictions of the experimental results. These predictions will be reported in the detailed PC Test Plans developed under applicable procedures.

5.2.2 Test Planning for Performance Confirmation

Performance confirmation test planning documents are developed to address requirements in the *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171386]). Currently, as required for site characterization, technical work plans are developed in accordance with AP-2.27Q, *Planning for Science Activities* ([DIRS 172108]), and contain information sufficient to describe the products supported by the test, the purpose and objectives of the test, the definition of the work scope, the applicability of quality assurance controls, an explanation of the scientific approach and technical methods, interface controls, and a list of mandatory hold points. A technical work plan is written for testing activities that require data collection or test apparatus configuration and subsequent observation or measurement that collect data known to support Project quality affecting work elements.

To plan performance confirmation testing and monitoring activities, AP-2.27Q ([DIRS 172108]) will be revised or another similar procedure developed that contains the elements listed below. Unlike during site characterization, the planning process for performance confirmation will need to account for specific parameter identification, expected ranges, variance limits, and the resulting reporting requirements. Therefore, at the appropriate stage of the Project, the performance confirmation planning processes will be controlled. For the purposes of this plan, the resulting planning documents will be referred to as PC Test Plans. Current science investigation test plans (written under the now decontrolled AP-SIII.7Q, *Scientific Investigation Laboratory and Field Testing* ([DIRS 159295])) and technical work plans that are identified as performance confirmation activities will be transitioned to PC Test Plans. PC Test Plans for those activities already begun during site characterization will be developed first, followed by planning for activities in later stages of the Project, according to a schedule commensurate with their need. Section 6 discusses schedule and provides an overview of the specific timing of the performance confirmation program.

The PC Test Plans will specify, as appropriate, the following:

- List of parameters to be measured
- 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 mitigations of hazards associated with the tests
- Software requirements
- Data acquisition
- Data management
- Control of samples
- Calibration requirements
- Potential sources of error or uncertainty, bounding tolerances or margins, including assumptions, as applicable
- Acceptance criteria for the results and data
- Defined ranges for the measured parameter (expected range and condition limits)
- Spatial and temporal test frequency
- Baseline information
- Anticipated changes to be observed or measured during the period of the tests
- Identification of what constitutes trends or variations beyond the anticipated range during the monitoring or testing period
- Reporting and action processes and requirements.

PC Test Plans will require evaluations to ensure that planned testing does not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives and is consistent with safe operation at the geologic repository operations and the SAR.

Appropriate accuracy and precision also need to be part of the test planning efforts and design of the measurement systems. Parameters to be monitored will require varying degrees of accuracy and precision to ensure significant deviations have been detected. Some of the new activities described in this plan may be so complex that they may need a formal preparedness assessment review prior to startup. Methods similar to those described in QAP-2-6, *Readiness Review* ([DIRS 170193]) establish responsibilities and process for such an assessment. The assessment will verify that specific work activity prerequisites, programmatic requirements, and program objectives have been satisfied prior to the start of a project phase, process, or activity subject to the Quality Assurance Requirements and Description (DOE 2004 [DIRS 171386]).

General repository planning related to development of the site is identified in the *Site Development Plan*, (DOE 2004 [DIRS 170191]). The repository configuration required to meet performance confirmation requirements is defined and described in design documents and drawings. Construction planning reflecting performance confirmation needs is described in the *Construction Execution Plan*, (DOE 2004 [DIRS 168857]).

5.2.3 Test Procedures, Implementing Documents, and Reports

To implement the performance confirmation activities described in the PC Test Plans, a hierarchical implementing process consisting of field work packages, technical procedures, scientific notebooks, test work authorizations, and work orders will be employed. At this level of planning, activity specific implementing controls and requirements will be developed and documented, including specific principal investigator requirements (e.g., test bed construction specifics, data collection requirements, or special equipment requirements), material controls (e.g., test interference and committed material reporting requirements), land access and environmental compliance requirements, specific safety and health requirements, and test construction and site operations requirements. In addition, this process allows for a system of checks, balances, and traceability including management, quality, safety, and the investigators. Evaluations of impact to emplaced waste, equipment exposure, and test equipment suitability for temperature and radiation levels will be conducted at this stage of planning.

Field Work Packages–Field work packages provide a detailed and controlled mechanism for field activity planning that identifies:

- Purpose and scope of the test
- Roles and responsibilities of interfacing organizations
- Project requirements for quality affecting and site disturbing testing activities
- Planned tracer, fluid, and materials usage
- Controls resulting from evaluations of potential impact from the activities on waste isolation and test-to-test interference
- Environmental, Safety and Health controls

- Identification and mitigation of hazards associated with the test to be performed
- Records requirements for the test.

Field work packages are typically not required for laboratory testing as those activities do not impact the site; generally do not require environmental or other permits; and are controlled under facility safety and health plans, laboratory chemical hygiene plans, and technical procedures.

A function of coordination is necessary to integrate field support requirements, quality requirements, environmental safety, and health requirements, and hazard analysis and controls into the field work packages, and assist in the permitting, estimating, and integrated scheduling. Field work packages and associated test work authorization documents are currently developed in accordance with AP-5.2Q, ([DIRS 168667]). This test coordination function must work closely with the performance confirmation organization described in Section 5.1 to ensure the successful planning and implementation of the program.

Technical Procedures and Scientific Notebooks for Laboratory and Field Testing–Technical procedures are used to describe the actual 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 and generally contain the following:

- Purpose and scope of the process
- Roles and responsibilities
- Procedure for implementation describing the step-by-step instructions that describe the technical requirements and the performer
- Listing of the equipment and hardware and software
- Qualification prerequisites
- Calibration requirements
- Control of samples
- Data acquisition and reduction
- Potential sources of error and uncertainty
- Acceptance criteria for results and data
- Records requirements and responsibilities for the specific process.

Scientific notebooks can complement the technical procedures for investigation activities. A scientific notebook is a defensible document detailing the acquisition of data where the chronologically detailed process must be clear and thorough enough to allow a comparably experienced investigator to replicate the experiment or study without recourse to the original investigator. Scientific notebooks are currently developed using AP-SIII.1Q, *Scientific Notebooks* ([DIRS 165688]).

Test Work Authorization and Work Orders for Field Test Implementation–Operations and test management authorization is an essential principle of integrated safety management and is used at the Site to initiate field work activities. The work authorization process is currently defined in AP-5.2Q ([DIRS 168667]), for testing activities and LP-2.23Q, *Work Request/Work Order Process* ([DIRS 170703]), for craft labor support. Worker involvement is key in the development of these written instructions necessary to identify the most efficient and safe methods to accomplish the work scope. This lowest level of planning for performance confirmation test activities consolidates task specific work scope, identifies the specific work location, identifies a person-in-charge at the worksite, identifies tools needed for the job, consolidates applicable permits required to perform the work, identifies special qualification or training requirements for the work (e.g., underground access training), and provides a task specific hazard checklist with personal protective equipment requirements. Work control and authorization will remain similar for the near term of the Project; however, it is anticipated that logistics related to site access and task-specific work control will evolve during the construction and operational phases of the Project.

Implementation Records, Data, and Reports–Records generated as a result of the test implementation will be handled, stored, and submitted to the Records Processing Center in accordance with AP-17.1Q, *Records Management* ([DIRS 172198]). Acquired and developed data resulting from performance confirmation testing and monitoring activities will be submitted to the Technical Data Management System in accordance with AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System* ([DIRS 168062]).

Periodically, during the implementation of site characterization activities, technical reports were written to capture the interpretations of results or conclusions of the investigations; to assemble related ideas into a single document; summarize the current state of knowledge on a scientific or engineering topic or suite of topics; and to summarize data, calculations, analyses, and models as documented in other products. The reports are currently prepared in accordance with LP-3.11Q ([DIRS 171187]). For performance confirmation test activities, similar methods will be used to summarize test activity progress. These reports would supplement the test review and reporting activities described previously in Section 4 of this plan.

5.2.4 Performance Confirmation Tests Initiated During Site Characterization

Several of the performance confirmation activities (or elements of the activities) defined in Section 3 of this plan were initiated or conducted during site characterization. The test planning and implementation process used for site characterization has already been applied to these activities and as described in Section 5.2.2. PC Test Plans will be written to place these activities (in part or in whole), as appropriate, into the performance confirmation program planning process described above.

Table 5-1 contains the list of performance confirmation activities conducted or initiated during site characterization, with a reference to governing technical work plans, scientific investigation work plans, and field work package(s), and a brief description of the work conducted during site characterization. Because the other nine performance confirmation activities have not yet begun, they are not included in the table. Multiple participants were often associated with a suite of testing activities, thereby requiring multiple test plans and field work packages. For almost all of the other performance confirmation activities not listed in Table 5-1, certain elements of their planned methodologies and measurement types have been used in past investigations, although not necessarily for the same parameter investigation or in the same depth or environment (e.g., around waste packages) that will be used in the future activities. For example, remote visual monitoring is being conducted in the Drift Scale Test using a trolley driven remote camera to look for evidence of rockfall and moisture. This is similar to the parameters to be investigated in the drift inspection activity. Although this ESF investigation was not conducted around real waste packages, further development of such a system will be required for the techniques that will be employed for remote monitoring of the waste packages and drift inspections in the emplacement drifts. Another example would be dust collection. Dust collection and analysis is being conducted within the existing tunnels using vacuum systems operated by hand. The purpose of the activity and the analysis may be the same for the performance confirmation activity of dust buildup monitoring; however, this is not the technique that will be employed for dust buildup monitoring using remote technology.

Table 5-1. Current Test Plans (or Technical Work Plans) and Field Work Plans

PERFORMANCE CONFIRMATION ACTIVITY TITLE	SUMMARY OF ONGOING OR PREVIOUSLY CONDUCTED WORK	CURRENT TEST PLAN (or TWP)*	CURRENT FWP*
SUBSURFACE MAPPING	Subsurface mapping activities conducted during site characterization including mapping for fracture and lithophysal characteristics gathered from the excavated walls of the ESF and/or ECRB Cross-Drift.	**SITP-02-ISM-001**, TSw Fracture and Lithophysal Studies - ISM **TWP-NBS-GS-000005**, Fracture and Lithophysal Studies	**FWP-ESF-PA-001**, Geologic Mapping
SEISMICITY MONITORING	This ongoing activity encompasses several aspects of seismological monitoring and analysis, including real-time earthquake monitoring, strong-motion data collection and analysis, seismic attenuation investigations, and characterization of earthquake source mechanics.	**SIP-UNR-027**, Southern Great Basin Seismic Network Operations	**FWP-SB-97-007**, Seismic Monitoring
CONSTRUCTION EFFECTS MONITORING	This ongoing program currently monitors for tunnel stability and the performance of the engineered ground support systems including use of strain data from gages installed on steel sets, extensometers in the tunnel walls, and convergence pin readings.	**SITP-03-EBS-002**, Test Plan for: Construction Monitoring Equipment Installation and Data Collection	**FWP-ESF-96-002**, Construction Monitoring in the ESF

Table 5-1. Current Test Plans (or Technical Work Plans) and Field Work Plans (Continued)

PERFORMANCE CONFIRMATION ACTIVITY TITLE	SUMMARY OF ONGOING OR PREVIOUSLY CONDUCTED WORK	CURRENT TEST PLAN (or TWP)*	CURRENT FWP*
PRECIPITATION MONITORING	This ongoing program currently consists of measuring, with known accuracy, the accumulation and timing of precipitation around Yucca Mountain using tipping bucket rain gauges.	**SIP-UNLV-030**, Precipitation Monitoring at Yucca Mountain **TWP-MGR-MM-000001**, Meteorological Monitoring and Data Analysis	**FWP-SB-99-002**, Surface Based Moisture Monitoring **FWP-SB-99-001**, Field Activities in Support of Meteorological Programs
SEEPAGE MONITORING	Current ongoing studies conducted in the ECRB Cross-Drift, in Alcove 7, and in the seepage niches are designed to detect seepage in sealed drift sections and to evaluate the drying effects of ventilation and construction activity on the underground moisture conditions. The existing network of atmospheric moisture monitoring in the ESF and cross drift monitors temperature, relative humidity, barometric pressure, and wind speed to measure the effects of ventilation, temperature, and tunnel activity at several locations in the ESF and ECRB Cross-Drift	**SITP-02-UZ-010**, Moisture Monitoring and Investigation and Alcove 7 Studies **SIP-UNLV-035**, Chemical Analysis for Alcove 8/Niche 3 Tracer Studies **SITP-02-UZ-001**, Moisture Monitoring in the ECRB Bulkheaded Cross Drift	**FWP-ESF-PA-004**, Moisture Studies in Sealed Drifts
SUBSURFACE WATER AND ROCK TESTING	Several site characterization activities from various regions of the tunnel were designed to conduct lab analysis of water and rock including tests to determine whether or not fluids containing bomb-pulse ^{36}Cl/chlorine traveled along fast travel pathways and reached the repository horizon.	**SIP-UNLV-026**, Ground Bomb-Pulse Chlorine-36 at the Proposed Yucca Mountain Repository Horizon: An Investigation of Previous Conflicting Results and Collection of New Data	**FWP-ESF-96-009**, Consolidated Sampling in the ESF
UNSATURATED ZONE TESTING	Ongoing activities consist of quantification of large-scale (~20 m) infiltration and seepage processes using Alcove 8 and Niche 3 in the ESF. These include an estimation of the relationships between permeability, water content, water potential for unsaturated flow in faults, fracture networks, and welded tuff.	**TWP-NBS-HS-00004**, Flow and Seepage Testing in Alcove 8/Niche 3	**FWP-ESF-PA-005**, Flow and Seepage Testing in Alcove 8 and Niche 3
SATURATED ZONE ALLUVIUM TESTING	The activities conducted during site characterization consists of hydraulic and single-hole tracer testing. Single-well hydraulic and tracer testing in NC-EWDP-19D1, the first of the Alluvial Testing Complex wells, was completed in April 2001, prior to the drilling of additional testing wells at the Alluvial Testing Complex location.	**SITP-02-SZ-003**, Test Plan for Alluvial Testing Complex, Single Well, Multi-Well, and Laboratory Studies **SIP-UNLV-034**, Chemical Analysis in Support of Yucca Mountain Studies	**FWP-SBD-99-002**, Alluvial Tracer Testing

Table 5-1. Current Test Plans (or Technical Work Plans) and Field Work Plans (Continued)

PERFORMANCE CONFIRMATION ACTIVITY TITLE	SUMMARY OF ONGOING OR PREVIOUSLY CONDUCTED WORK	CURRENT TEST PLAN (or TWP)*	CURRENT FWP*
CORROSION TESTING	Ongoing activities in this area consist of a number of tests that are designed to provide information on the performance of the materials of construction of the waste package and the drip shield including general corrosion testing, stress corrosion cracking and physical metallurgy.	**SITP-02-WP-001**, Waste Package and Drip Shield Materials Testing	N/A - Controlled with laboratory safety plans and technical procedures
WASTE FORM TESTING	Ongoing activities in this area consist of activities to improve the understanding of spent nuclear fuel and radionuclide mobilization performance and to provide data that can be used for model development, validation, and confirmation by determining the reaction behavior of spent nuclear fuel, measuring the extent of radionuclide release, characterizing generated colloids from spent nuclear fuel, comparing the releases for the different configurations, and developing sufficient understanding of the kinetics and mechanisms of fuel reaction to provide accurate guidance and input data to the source term for sparingly soluble radionuclides in repository models of fuel corrosion and transport.	**TWP-WIS-MD-000008**, Waste Form Degradation Modeling, Testing, and Analyses in Support of LA **SITP-02-WF-001**, Long-Term Studies of the Degradation and Nuclide Release from Commercial Spent Fuel and Fuel Rod Segments **SITP-02-WF-002**, Longer-Term Studies of the Degradation and Radionuclide Release from Defense High-Level Waste (DHLW) Glass	N/A - Controlled with laboratory safety plans and technical procedures

Sources: Brandt 2004, SIP-UNLV-030 [DIRS 170246]; Brune 2004, SIP-UNR-027 [DIRS 170249]; BSC 2002, SITP-02-SZ-003 [DIRS 158198]; BSC 2002, SITP-02-UZ-001 [DIRS 158187]; BSC 2002, SITP-02-UZ-010 [DIRS 158189]; BSC 2002, SITP-02-WF-002 [DIRS 164401]; BSC 2002, SITP-02-WP-001 [DIRS 170209]; BSC 2003, TWP-NBS-GS-000005 [DIRS 170211]; BSC 2003, SITP-03-EBS-002 [DIRS 170210]; BSC 2003, TWP-MGR-MM-000001 [DIRS 163158]; BSC 2004, TWP-NBS-HS-000004 [DIRS 170212]; BSC 2004, TWP-WIS-MD-000008 [DIRS 167796]; Bureau of Reclamation 2002, SITP-02-ISM-001 [DIRS 158182]; Daniels 2004, SIP-UNLV-035 [DIRS 170248]; ORD 2003, FWP-ESF-PA-001 [DIRS 170203]; ORD 2004, FWP-ESF-PA-004 [DIRS 170204]; ORD 2004, FWP-ESF-PA-005 [DIRS 170205]; YMP 1999, FWP-ESF-96-002 [DIRS 147872]; Finn 2002, SITP-02-WF-001 [DIRS 170214]; ORD 2002, FWP-SB-99-001 [DIRS 161578]; Page 2004, SIP-UNLV-029 [DIRS 170245]; Stetzenbach 2004, SIP-UNLV-026 [DIRS 170244]; USGS 2001 [DIRS 158199]; USGS 2002 [DIRS 158195]; Wengatz 2004 [DIRS 170247]; YMP 2001 [DIRS 170208]; YMP 2002 [DIRS 170207]; YMP 1999 [DIRS 150629]; YMP 2000 [DIRS 150630]; and YMP 2002 [DIRS 169664]

NOTE:* The columns containing the current test plan or field work plan are not intended to be comprehensive or complete, but provides a representative group of currently base lined documents that are used for the implementation of test activities similar to the performance confirmation activities described in this plan. Therefore, there is not always a one-to-one correlation between future performance confirmation activities and existing testing program activities.

6. SCHEDULE

The previous section described the implementation of the testing program. This section outlines the schedule for the activities. Although there is discussion within the individual activity descriptions in Section 3 on activity start times and durations, this section places the 11 activities that began during site characterization, and the other nine that have not yet begun, in timeline with other Project milestones and activities.

The 20 performance confirmation activities identified herein have been scheduled on bases commensurate with the current stage of the Project. These 20 activities fall into three timeframe or timeline groups:

- Preconstruction (continuation of activities (or similar activities)) initiated during site characterization)
- Construction (after receipt of a construction authorization)
- Operation/monitoring (Post-waste emplacement).

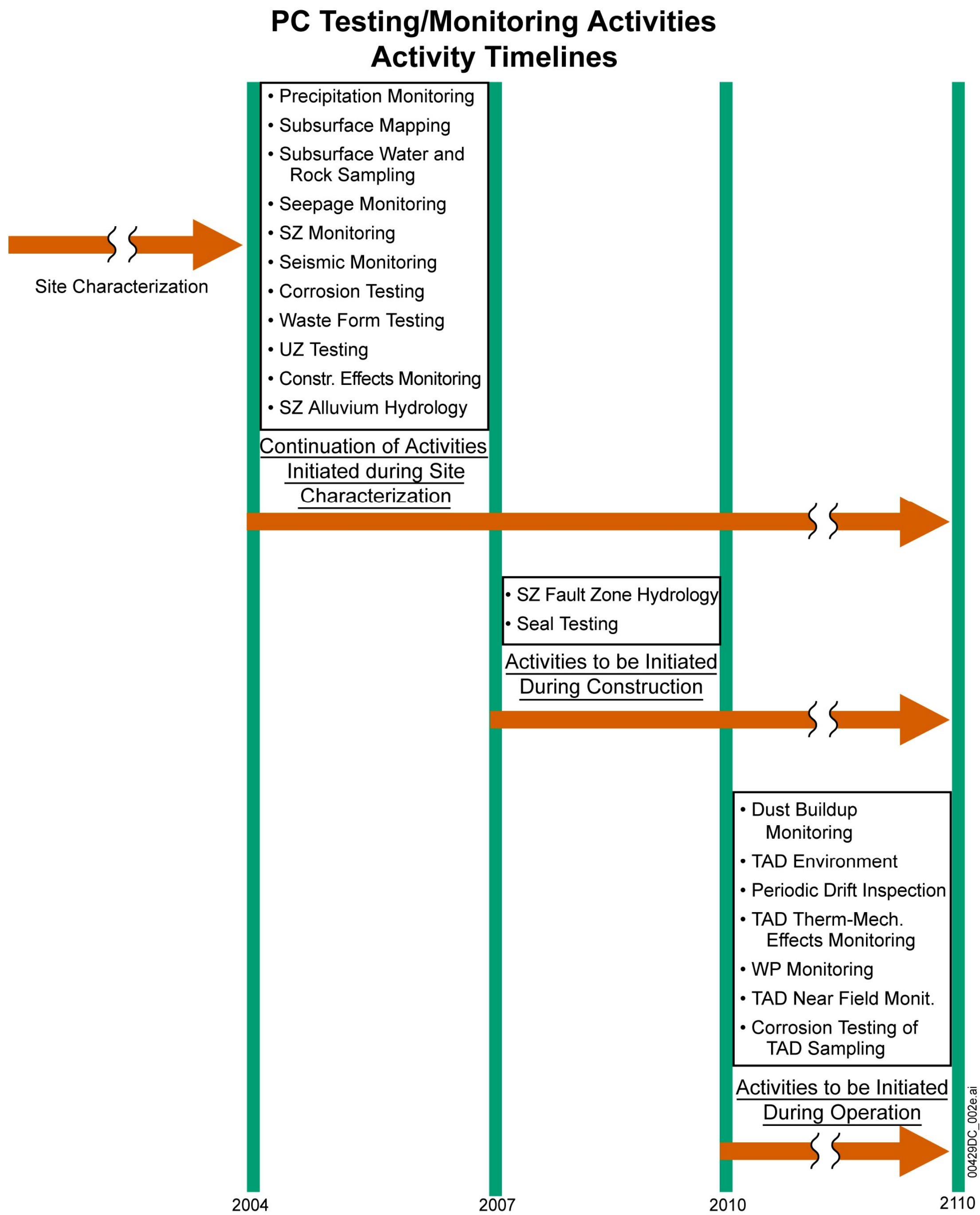
These three activity group timelines are shown in Figure 6-1. Activities that are in preconstruction and that will be a continuation of those initiated during site characterization have a greater level of planning and scheduling detail than those in later phases of the Project. Some of this schedule detail was captured in the Section 3 discussion for each individual activity. Additional schedule details are contained for the ongoing activities in their existing scientific investigation test plans or technical work plans (Table 5-1) and will be captured in the PC Test Plans once written for these activities.

Detailed schedules are also captured in the Project's multi-year planning process (for ongoing activities) and may be detailed in individual PC Test Plans. Detailed schedules will reflect that many of the monitoring activities will be relatively quick to conduct and will be performed intermittently during the monitoring period. The individual test durations and sequencing during the monitoring period will be developed later and described in the products mentioned above. The phased nature of repository development allows progressive development of these schedules. Schedules for activities continuing from site characterization are well understood and will be integrated into early construction and operations planning products, while planning for some construction period activities requires finalization, and planning for operational period activities is mostly at a conceptual stage. Future revisions of this plan will provide additional details and more complete schedules, depending on the timing of the revision compared to the stage of the Project.

For an overall perspective on test planning, Figure 6-2 (schedule through year 2011) and Figure 6-3 (schedule through year 2110) are included. These schedules provide perspective on test timing by showing selected major program milestones and related activity milestones.

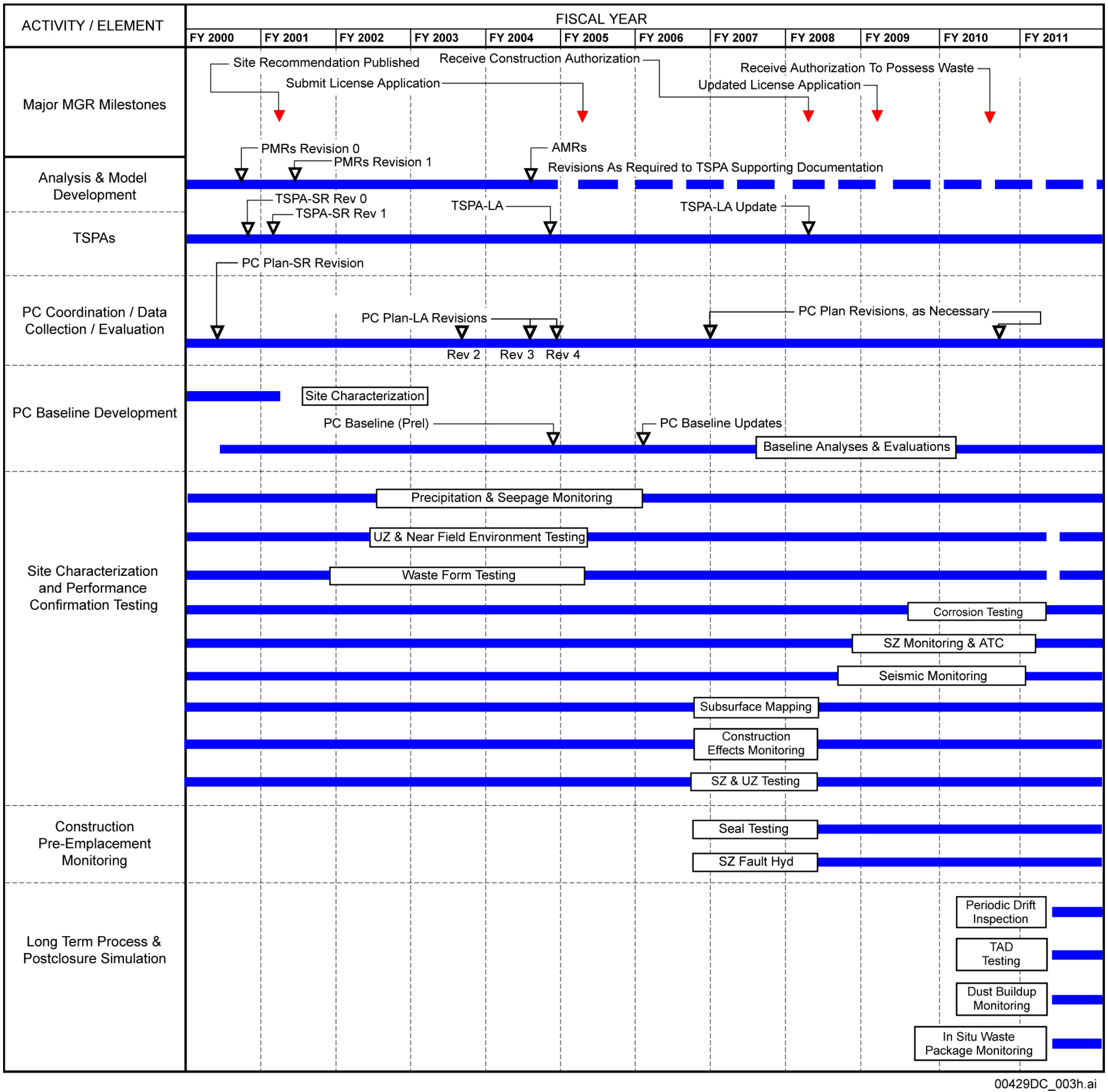
These schedules assume a period of 100 years for the performance confirmation program. The program will continue until repository closure and decommissioning.

The monitoring period and the closure date are still under consideration. The waste package monitoring program will continue for as long as practical until permanent closure (10 CFR 63.134(d) [DIRS 156605]), and the performance confirmation program will continue to evolve as schedules change to ensure that work continues to evaluate repository performance.



NOTE: Activities start with the origination of the arrow (i.e., construction start = 2007, operation start = 2010), except in the case of the first box, as site characterization activities have been going on well before 2004.

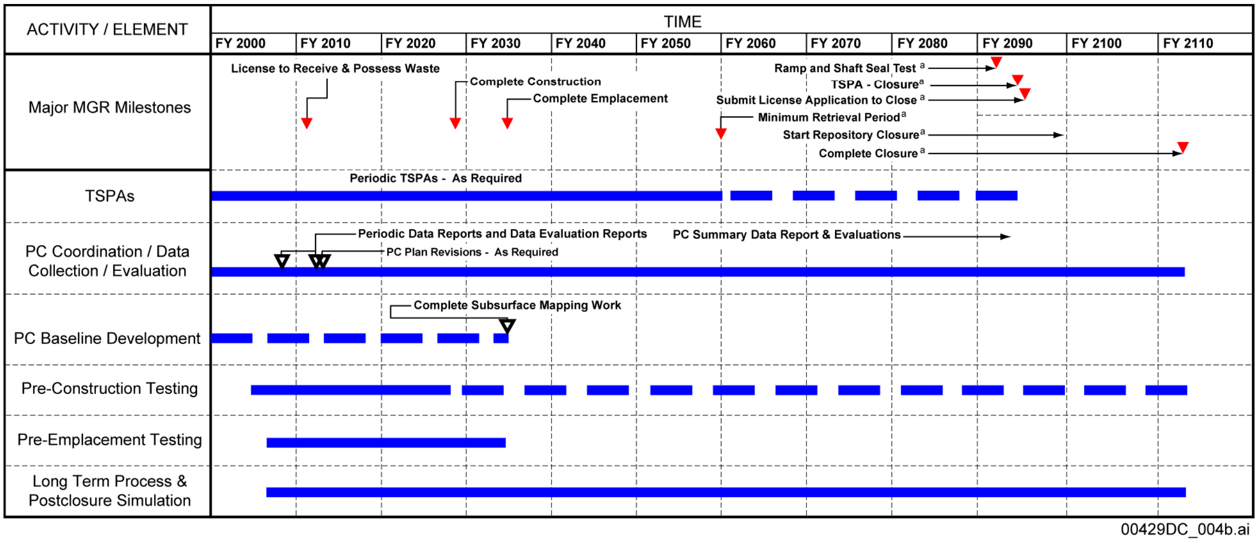
Figure 6-1. Temporal Breakdown of Performance Confirmation Activities



NOTES: Activities include planning procurement and installation of instruments; AMR = analysis model report; MGR= mined geologic repository; PC = performance confirmation; FY = fiscal year; LA = License application; PMR = process model report; SR = site recommendation; SZ = saturated zone; TAD = thermally accelerated drift; TSPA = total system performance assessment; UZ = unsaturated zone.

Site Characterization activities shown continuing from the left side of the schedule are ongoing performance confirmation testing activities.

Figure 6-2. Schedule for the Performance Confirmation Program and Major Yucca Mountain Project Milestones



NOTES: The duration of the repository monitoring period and the closure date are still under consideration. The 2110 milestone date shown reflects a presumed 100-year period for preclosure operations.

Activities include planning procurement and installation of instruments; MGR= mined geologic repository; PC = performance confirmation; FY = fiscal year; TSPA = total system performance assessment.

Performance Confirmation Coordination, Data Collection, Evaluation, and Long-Term Process and Postclosure Simulation are shown purposefully to complete closure, not to support the License Application to Close, but to show that certain closure activities may be monitored and confirmed not to impact the repository ability to isolate waste.

Dashed lines on PC Baseline Development represent the establishment of a preliminary baseline during site characterization, with refinement through construction. The dash line in Pre-Construction Testing represents on-going monitoring initiated during pre-construction, that continues through closure.

Figure 6-3. Long-Term Performance Confirmation Program Schedule

7. REFERENCES

7.1 DOCUMENTS CITED

101367 Albin, A.L.; Singleton, W.L.; Moyer, T.C.; Lee, A.C.; Lung, R.C.; Eatman, G.L.W.; and Barr, D.L. 1997. *Geology of the Main Drift - Station 28+00 to 55+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Milestone SPG42AM3. Denver, Colorado: Bureau of Reclamation and U.S. Geological Survey. ACC: MOL.19970625.0096.

170214 ANL (Argonne National Laboratory) 2002. *Test Plan Long-Term Studies of the Degradation and Nuclide Release from Commercial Spent Fuel and Fuel Rod Segments*. SITP-02-WF-001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020402.0445.

100029 Barr, D.L.; Moyer, T.C.; Singleton, W.L.; Albin, A.L.; Lung, R.C.; Lee, A.C.; Beason, S.C.; and Eatman, G.L.W. 1996. *Geology of the North Ramp — Stations 4+00 to 28+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970106.0496.

101191 Beason, S.C.; Turlington, G.A.; Lung, R.C.; Eatman, G.L.W.; Ryter, D.; and Barr, D.L. 1996. *Geology of the North Ramp - Station 0+60 to 4+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada*. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970106.0449.

170246 Brandt, A. 2004. *Precipitation Monitoring at Yucca Mountain*. Document Number: SIP-UNLV-030, Rev. 0. Las Vegas, Nevada: University and Community College System of Nevada. ACC: MOL.20040629.0238.

155640 BSC (Bechtel SAIC Company) 2001. *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier*. ANL-EBS-MD-000001 REV 00 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010724.0082.

158464 BSC 2001. *Repository Design, Closure and Sealing Typical Details*. DWG-SCS-MG-000002 REV A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020102.0128.

158207 BSC 2001. *Supporting Rock Fall Calculation for Drift Degradation: Quantification of Uncertainties*. CAL-EBS-MD-000022 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20011213.0238.

158187 BSC 2001. *Test Plan for: Moisture Monitoring in the ECRB Bulkheaded Cross Drift*. SITP-02-UZ-001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20011018.0011.

158375 BSC 2002. *Drift-Scale Coupled Processes (DST and THC Seepage) Models*. MDL-NBS-HS-000001 REV 01 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020312.0156.

160161 BSC 2002. *Geochemical Interactions in Failed Co-Disposal Waste Packages for N Reactor and Ft. St. Vrain Spent Fuel and the Melt and Dilute Waste Form*. ANL-EBS-PA-000007 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020827.0001.

159124 BSC 2002. *Geologic Framework Model (GFM2000)*. MDL-NBS-GS-000002 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020530.0078.

158730 BSC 2002. *Mineralogic Model (MM3.0) Analysis Model Report*. MDL-NBS-GS-000003 REV 00 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020423.0151.

159530 BSC 2002. *Rock Properties Model Analysis Model Report*. MDL-NBS-GS-000004 REV 00 ICN 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020429.0086.

170211 BSC 2002. *Technical Work Plan for: Fracture and Lithophysal Studies*. TWP-NBS-GS-000005 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20021113.0214.

158198 BSC 2002. *Test Plan for Alluvial Testing Complex – Single-Well, Multi-Well, and Laboratory Studies*. SITP-02-SZ-003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020404.0081.

164401 BSC 2002. *Test Plan for Long-Term Studies of the Degradation and Radionuclide Release from Defense High-Level Waste (DHLW) Glass*. SITP-02-WF-002, Rev. 00. [Las Vegas, Nevada]: Bechtel SAIC Company. ACC: MOL.20020402.0444.

158189 BSC 2002. *Test Plan for: Moisture Monitoring Investigations and Alcove 7 Studies*. SITP-02-UZ-010 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020117.0199.

170209 BSC 2002. *Test Plan for: Waste Package and Drip Shield Materials Testing*. SITP-02-WP-001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020304.0050.

160771 BSC 2002. *Thermal Testing Measurements Report*. ANL-NBS-HS-000041 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20021004.0314.

165564 BSC 2003. *Abstraction of Drift Seepage*. MDL-NBS-HS-000019 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031112.0002.

162199 BSC 2003. *Aging and Phase Stability of Waste Package Outer Barrier*. ANL-EBS-MD-000002 REV 01 ICN 0. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030807.0004.

165991 BSC 2003. *Analysis of Infiltration Uncertainty.* ANL-NBS-HS-000027 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031030.0003.

164475 BSC 2003. *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*. CAL-EBS-MD-000030 REV 00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031001.0012.

166274 BSC 2003. *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, NV*. MDL-MGR-GS-000003 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031201.0001.

162050 BSC 2003. *Drift-Scale Coupled Processes (DST and THC Seepage) Models*. MDL-NBS-HS-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030804.0004.

164889 BSC 2003. *Drift-Scale Radionuclide Transport.* MDL-NBS-HS-000016 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030902.0009.

164890 BSC 2003. *Drift Scale THM Model*. MDL-NBS-HS-000017 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031014.0009.

163693 BSC 2003. *DSNF and Other Waste Form Degradation Abstraction*. ANL-WIS-MD-000004 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030711.0002.

166834 BSC 2003. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030916.0010; DOC.20031222.0002; DOC.20031222.0001.

168343 BSC 2003. *Analysis of Geochemical Data for the Unsaturated Zone*. ANL-NBS-HS-000017 REV 00 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020314.0051; DOC.20031015.0006.

166509 BSC 2003. *Calibrated Properties Model*. MDL-NBS-HS-000003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030219.0001; DOC.20031014.0011.

165802 BSC 2003. GFM2000 *Representation in the VULCAN Software System*. 800-00C-TU00-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20030922.0005.

161759 BSC 2003. *Hydrogen Induced Cracking of Drip Shield*. ANL-EBS-MD-000006 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030304.0003.

166498 BSC 2003. *Mountain-Scale Coupled Processes (TH/THC/THM)*. MDL-NBS-HS-000007 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031216.0003.

163228 BSC 2003. *Radionuclide Transport Models Under Ambient Conditions*. MDL-NBS-HS-000008 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031201.0002.

167209 BSC 2003. *Saturated Zone In-Situ Testing*. ANL-NBS-HS-000039 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040128.0003.

166183 BSC 2003. *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability*. 800-K0C-TEG0-00600-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031125.0002.

163158 BSC 2003. *Technical Work Plan for: Meteorological Monitoring and Data Analysis*. TWP-MGR-MM-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030328.0005.

170210 BSC 2003. *Test Plan for: Construction Monitoring Equipment Installation and Data Collection*. SITP-03-EBS-002 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030626.0005.

166296 BSC 2003. *Total System Performance Assessment-License Application Methods and Approach*. TDR-WIS-PA-000006 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031215.0001.

161317 BSC 2003. *WAPDEG Analysis of Waste Package and Drip Shield Degradation*. ANL-EBS-PA-000001 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031208.0004.

166845 BSC 2003. *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary.* MDL-EBS-PA-000004 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031222.0012.

161236 BSC 2003. *General Corrosion and Localized Corrosion of the Drip Shield*. ANL-EBS-MD-000004 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030626.0001.

167970 BSC 2004. *Abstraction of Drift Seepage*. MDL-NBS-HS-000019 REV 00 ICN 01 Errata 001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031112.0002; DOC.20040223.0001.

166604 BSC 2004. *Closure and Sealing Preliminary Design Calculation*. 800-KMC-MGR0-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040113.0003.

168217 BSC 2004. *Commercial SNF Waste Package Design Report*. 000-00C-DSU0-02800-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040315.0007.

167321 BSC 2004. *CSNF Waste Form Degradation: Summary Abstraction*. ANL-EBS-MD-000015 REV 01 [Errata 002]. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030708.0004; DOC.20031224.0001; DOC.20040202.0002.

167619 BSC 2004. *Defense HLW Glass Degradation Model*. ANL-EBS-MD-000016 REV 01 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040223.0006.

168550 BSC 2004. *Drift Degradation Analysis.* ANL-EBS-MD-000027 REV 02, Errata 1. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040325.0002; DOC.20030709.0003.

170338 BSC 2004. *Drift-Scale Coupled Processes (DST and TH Seepage) Models*. MDL-NBS-HS-000015 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20040712.0194.

168848 BSC 2004. *Drift-Scale Coupled Processes (DST and THC Seepage) Models*. MDL-NBS-HS-000001 REV 02 Errata 002. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030804.0004; DOC.20040219.0002; DOC.20040405.0005.

167973 BSC 2004. *Drift Scale THM Model*. MDL-NBS-HS-000017 REV 00 ICN 01 Errata 001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031014.0009; DOC.20040223.0002.

167280 BSC 2004. *Emplacement and Retrieval System Description Document*. 800-3YD-HE00-00100-000-001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040302.0008.

167461 BSC 2004. *Engineered Barrier System: Physical and Chemical Environment Model.* ANL-EBS-MD-000033 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040212.0004.

168889 BSC 2004. *Evaluation of Emplacement Drift Stability for KTI Resolutions*. 800-KMC-SSE0-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040520.0001.

170212 BSC 2004. *Flow and Seepage Testing in Alcove 8/Niche3*. TWP-NBS-HS-000004 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040329.0005.

169339 BSC 2004. *Geochemical and Isotopic Constraints on Groundwater Flow Directions, Mixing, and Recharge at Yucca Mountain.* ANL-NBS-HS-000021 REV 01 [Errata 001]. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040412.0003; DOC.20040212.0003.

169056 BSC 2004. *In-Situ Field Testing of Processes*. ANL-NBS-HS-000005 REV 02 Errata 001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031208.0001; DOC.20040412.0006.

163056 BSC 2004. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040301.0004.

169218 BSC 2004. *Natural Analogue Synthesis Report.* TDR-NBS-GS-000027 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040524.0008.

169356 BSC 2004. *Probability Analysis of Corrosion Rates for Waste Package Materials.* ANL-DSD-MD-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040506.0004.

170000 BSC 2004. *Seepage Model for PA Including Drift Collapse*. MDL-NBS-HS-000002 REV 02 Errata 2. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030709.0001; DOC.20040512.0002; DOC.20040615.0004.

169051 BSC 2004. *Site Scale Saturated Zone Flow Model*. MDL-NBS-HS-000011 REV 01 Errata 001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040126.0004; DOC.20040415.0001.

169053 BSC 2004. *Site-Scale Saturated Zone Transport.* MDL-NBS-HS-000010 REV 01 [Errata 002]. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040126.0003; DOC.20040325.0001; DOC.20040412.0007.

169042 BSC 2004. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material.* ANL-EBS-MD-000005 REV 01 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040318.0010.

168869 BSC 2004. *Surveying and Removal of Radiological Contamination from External Surfaces of Waste Packages.* 100-M0C-MR00-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040413.0047.

167796 BSC 2004. *Technical Work Plan for Waste Form Degradation Modeling, Testing, and Analyses in Support of LA.* TWP-WIS-MD-000008 REV 02 ICN 04. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040218.0001.

168504 BSC 2004. *Total System Performance Assessment (TSPA) Model/Analysis for the License Application*. MDL-WIS-PA-000004 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. TBV-5947

168720 BSC 2004. *Ventilation Model and Analysis Report*. ANL-EBS-MD-000030 REV 03 ICN 03 Errata 2. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031216.0002; DOC.20040202.0004; DOC.20040325.0003.

169734 BSC 2004. *Yucca Mountain Site Description.* TDR-CRW-GS-000001 REV 02 ICN 01. Two volumes. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040504.0008; Replacement for 168845.

169617 BSC 2004. *Abstraction of Drift-Scale Coupled Processes.* MDL-NBS-HS-000018 REV 00 Errata 002. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031223.0004; DOC.20040223.0003; DOC.20040512.0001.

158182 Bureau of Reclamation. 2002. *Test Plan for: TSW Fracture and Lithophysal Studies*. SITP-02-ISM-001 REV 00. Las Vegas, Nevada: U.S. Bureau of Reclamation. ACC: MOL.20020205.0004.

101539 CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1997. *Ambient Characterization of the Drift Scale Test Block.* BADD00000-01717-5705-00001 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980416.0689.

146917 CRWMS M&O 1997. *Drift Scale Test Design and Forecast Results.* BAB000000-01717-4600-00007 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980710.0155.

111115 CRWMS M&O 1998. *Drift Scale Test As-Built Report.* BAB000000-01717-5700-00003 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990107.0223.

108306 CRWMS M&O 1998. *Drift Scale Test Progress Report No. 1.* BAB000000-01717-5700-00004 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990209.0240.

103731 CRWMS M&O 1998. *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada.* Milestone SP32IM3, September 23, 1998. Three volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981207.0393.

129261 CRWMS M&O 1999. *Single Heater Test Final Report.* BAB000000-01717-5700-00005 REV 00 ICN 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000103.0634.

103086 CRWMS M&O 1999. *Subsurface Closure & Seal System Description Document*. BCA000000-01717-1705-00012 REV 01. Two volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990713.0240.

144992 CRWMS M&O 2000. *Closure Seal Locations and Geologic Environment Study.* TDR-SCS-MG-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000122.0037.

145033 CRWMS M&O 2000. *Closure Seal Materials and Configuration.* TDR-SCS-MG-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000124.0136.

150624 CRWMS M&O 2000. *Repository Closure and Sealing Approach*. ANL-SCS-MG-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000714.0553.

149639 CRWMS M&O 2000. *Supporting Rock Fall Calculation for Drift Degradation: Drift Reorientation with No Backfill.* CAL-EBS-MD-000010 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000823.0003.

151945 CRWMS M&O 2000. *Yucca Mountain Site Description*. TDR-CRW-GS-000001 REV 01 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001003.0111.

170248 Daniels, J. 2004. *Chemical Analyses for Alcove 8/Niche 3 Tracer Studies*. Document Number: SIP-UNLV-035, Rev. 0. Las Vegas, Nevada: University and Community College System of Nevada. ACC: MOL.20040629.0234.

170250 DOE (U.S. Department of Energy) [1997]. *The Requirements-Based Surveillance and Maintenance Review Guide*. DOE/EM-0341. Washington, D.C.: U.S. Department of Energy, Office of Environmental Management. ACC: MOL.20040629.0233.

100282 DOE 1988. *Site Characterization Plan Yucca Mountain Site, Nevada Research and Development Area, Nevada.* DOE/RW-0199. Nine volumes. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: HQO.19881201.0002.

170253 DOE 1999. *Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites*. Washington, D.C.: U.S. Department of Energy, Office of Environmental Restoration. ACC: MOL.20040629.0311.

170252 DOE 1999. *EM Corporate Data Collection Guidance for the Interim Data Management System (IDMS) and the Analysis and Visualization System (AVS)*. Revision 2.0. Washington, D.C.: U.S. Department of Energy. ACC: MOL.20040629.0312.

170254 DOE 1999. *Technical Guidance for the Long-Term Monitoring of Natural Attenuation Remedies at Department of Energy Sites*. Washington, D.C.: U.S. Department of Energy, Office of Environmental Restoration. ACC: MOL.20040629.0310.

170255 DOE 2002. *Guidance for Optimizing Ground Water Response Actions at Department of Energy Sites*. Washington, D.C.: U.S. Department of Energy, Office of Environmental Management. ACC: MOL.20040629.0309.

155943 DOE 2002. *Yucca Mountain Science and Engineering Report*. DOE/RW-0539, Rev. 1. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020404.0042.

171341 DOE 2004. *Augmented Quality Assurance Program (AQAP)*. DOE/RW-0565. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040813.0001.

168857 DOE 2004. *Construction Execution Plan.* 000-PLN-MGR0-00700-000-000. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: ENG.20040211.0005.

171386 DOE 2004. *Quality Assurance Requirements and Description*. DOE/RW-0333P, Rev. 16. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040823.0004.

170191 DOE 2004. *Site Development Plan.* 000-PLN-MGR0-00100-000-001. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: ENG.20040217.0006.

157677 Eatman, G.L.W.; Singleton, W.L.; Moyer, T.C.; Barr, D.L.; Albin, A.L.; Lung, R.C.; and Beason, S.C. 1997. *Geology of the South Ramp - Station 55+00 to 78+77, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada*. Denver, Colorado: U.S. Department of Energy. ACC: MOL.19980127.0396.

163435 EPRI (Electric Power Research Institute) 2001. *Performance Confirmation for the Candidate Yucca Mountain High-Level Nuclear Waste Repository*. EPRI TR-1003032. Palo Alto, California: Electric Power Research Institute. TIC: 254361.

170143 Gibbons, R.D. 1994. *Statistical Methods for Groundwater Monitoring*. New York, New York: John Wiley & Sons. TIC: 256077.

172321 Hamilton-Ray, B.V. 2004. "Contracting Office Authorization for Bechtel SAIC Company, LLC (BSC), Improvements and Refinements in the Technical Bases that Support the Safety Analysis Report (SAR); Ltr 05-001 - Contract Number DE-AC28-01RW12101." Letter from B.V. Hamilton-Ray (DOE/ORD) to J.T. Mitchell, Jr. (BSC), October 29, 2004.

157634 Keeney, R.L. and Raiffa, H. 1976. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. New York, New York: John Wiley & Sons. TIC: 208907.

159069 Lin, W.; Blair, S.C.; Wilder, D.; Carlson, S.; Wagoner, J.; DeLoach, L.; Danko, G.; Ramirez, A.L.; and Lee, K. 2001. *Large Block Test Final Report*. UCRL-ID-132246, Rev. 2. Livermore, California: Lawrence Livermore National Laboratory. TIC: 252918.

170294 Mitchell, J.T. 2004. “Contract No. DE-AC28-01RW12101 - Response to Letter Dated April 23, 2004, Regarding Plan for Providing Definition and Interfaces of Testing and Monitoring Program.” Letter from J.T. Mitchell, Jr. (BSC) to W.J. Arthur, III (DOE/ORD), May 7, 2004, DJW:bm-0507041499, with enclosure. ACC: MOL.20040616.0647.

170504 Mitchell, J.T., Jr. 2004. "Contract No. DE-AC28-01RW12101 - Response to Rejected Deliverable Transmittal on the 'Performance Confirmation Plan REV 03', Deliverable Pad 205." Letter from J.T. Mitchell, Jr. (BSC) to W.J. Arthur, III (DOE/ORD), June 4, 2004, DJW/JTM/bm - 0527041774, with enclosures. ACC: MOL.20040712.0190.

149850 Mongano, G.S.; Singleton, W.L.; Moyer, T.C.; Beason, S.C.; Eatman, G.L.W.; Albin, A.L.; and Lung, R.C. 1999. *Geology of the ECRB Cross Drift - Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada*. [Deliverable SPG42GM3]. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20000324.0614.

163274 NRC (U.S. Nuclear Regulatory Commission) 2003. *Yucca Mountain Review Plan, Final Report*. NUREG-1804, Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 254568.

170243 NRC 2004. *Risk Insights Baseline Report.* Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. ACC: MOL.20040629.0235.

161578 ORD (Office of Repository Development) 2002. *Field Activities in Support of Meteorological Programs*. FWP-SB-99-001, Rev. 1. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20030122.0036.

170203 ORD 2003. *Geologic Mapping*. Field Work Package FWP-ESF-PA-001, Rev. 0. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: SIT.20030721.0003.

170205 ORD 2004. *Flow and Seepage Testing in Alcove 8 and Niche 3*. Field Work Package FWP-ESF-PA-005, Rev. 0. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: SIT.20040407.0002.

170204 ORD 2004. *Moisture Studies in Sealed Drifts (ECRB and Alcove 7)*. Field Work Package FWP-ESF-PA-004, Rev. 0. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: SIT.20040407.0001.

170245 Page, H.S. 2004. *Ground Water Level Measurements in Selected Boreholes Near the Site of the Proposed Repositor*y. Document Number: SIP-UNLV-029, Rev. 0. Las Vegas, Nevada: University and Community College System of Nevada. ACC: MOL.20040629.0237.

165976 Peterman, Z. 2001. "Letter Report on Dust Geochemistry." Letter from Z. Peterman (USGS) to N. Kramer, September 7, 2001, with attachment. ACC: MOL.20011004.0234.

165975 Peterman, Z.E.; Hudson, D.; and Harrington, B. 2002. *Analyses of Water Soluble Anions and Cations in Dust from the Exploratory Studies Facility (Supplement to Letter Report of September 7, 2001)*. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20020430.0259.

162819 Peterman, Z.E.; Paces, J.B.; Neymark, L.A.; and Hudson, D. 2003. "Geochemistry of Dust in the Exploratory Studies Facility, Yucca Mountain, Nevada." *Proceedings of the 10th International High-Level Radioactive Waste Management Conference (IHLRWM), March 30-April 2, 2003, Las Vegas, Nevada*. Pages 637-645. La Grange Park, Illinois: American Nuclear Society. TIC: 254559.

106702 Rogers, A.M.; Harmsen, S.C.; Corbett, E.J.; Priestly, K.; and dePolo, D. 1991. "The Seismicity of Nevada and Some Adjacent Parts of the Great Basin." Chapter 10 of *The Geology of North America Decade Map.* Volume 1. Boulder, Colorado: Geological Society of America. TIC: 243190.

170244 Stetzenbach, K. 2003. *Bomb-Pulse Chlorine-36 at the Proposed Yucca Mountain Repository Horizon: An Investigation of Previous Conflicting Results and Collection of New Data*. Document Number: SIP-UNLV-026, Rev. 0. Las Vegas, Nevada: University and Community College System of Nevada. ACC: MOL.20040629.0240.

158199 USGS (U.S. Geological Survey) 2001. *Test Plan for: Nye County EWDP Borehole Lithostratigraphy*. SITP-02-SZ-001 REV 00. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20020204.0145.

158195 USGS 2002. *Test Plan for: Hydrologic/Hydrochemistry Studies in Cooperation with Nye County EWDP.* SITP-02-SZ-002 REV 00. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20020205.0003.

166518 USGS 2003. *Simulation of Net Infiltration for Modern and Potential Future Climates.* ANL-NBS-HS-000032 REV 00 ICN 02. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20011119.0334; DOC.20031014.0004; DOC.20031015.0001.

168473 USGS 2004. *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model.* ANL-NBS-HS-000034 REV 01. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20020209.0058; MOL.20020917.0136; DOC.20040303.0006.

170249 von Seggern, D. 2004. *Southern Great Basin Seismic Network Operations*. Document Number: SIP-UNR-027, Rev. 0. [Reno], Nevada: University and Community College System of Nevada. ACC: MOL.20040629.0239.

159532 von Seggern, D.H. and Smith, K.D. 1997. *Seismicity in the Vicinity of Yucca Mountain, Nevada, for the Period October 1, 1995, to September 30, 1996*. Milestone Report SPT38AM4. [Reno, Nevada]: University of Nevada, [Reno], Seismological Laboratory. ACC: MOL.19981124.0334.

172213 Watson, W.W, 2004. "Meeting Notes: Assessment of the Proposed Performance Confirmation Program Relevance to TSPA-LA." Interoffice memorandum from W.W. Watson (BSC) to File, October 27, 2004, 1018043622, DJW/WWW/bm, with enclosure. ACC: MOL.20041027.0247.

170247 Wengatz, I. 2004. *Chemical Analyses in Support of Yucca Mountain Studies*. Document Number: SIP-UNLV-034, Rev. 0. Las Vegas, Nevada: University and Community College System of Nevada. ACC: MOL.20040629.0236.

100522 YMP (Yucca Mountain Site Characterization Project) 1997. *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain.* Topical Report YMP/TR-002-NP, Rev. 1. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19971016.0777.

147872 YMP 1999. *Construction Monitoring in the Exploratory Studies Facility*. Field Work Package FWP-ESF-96-002, Rev. 4. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19990811.0078.

150629 YMP 1999. *Surface-Based Borehole Instrumentation and Monitoring*. Field Work Package FWP-SB-97-009, Rev. 1. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19991014.0231.

150630 YMP 2000. *Surface-Based Moisture Monitoring*. Field Work Package FWP-SB-99-002, Rev. 1. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.20000214.0312.

170208 YMP 2001. *Alluvial Tracer Testing*. Field Work Package FWP-SBD-99-002, Rev. 1. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.20011217.0135.

170207 YMP 2002. *Nye County Early Warning Drilling Program (EWDP) Phase IV Drilling*. Field Work Package FWP-SBD-99-001, Rev. 4. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.20021022.0138.

169664 YMP 2002. *Seismic Monitoring*. Field Work Package FWP-SB-97-007, Rev. 3. Las Vegas, Nevada: U.S. Department of Energy, Yucca Mountain Site Characterization Office. ACC: MOL.20020906.0241.

7.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

156605 10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

156671 66 FR 55732. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, NV, Final Rule. 10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 60, 61, 63, 70, 72, 73, and 75. Readily available.

172197 AP-7.5Q, Rev. 002, ICN 001. *Establishing Deliverable Acceptance Criteria and Submitting and Reviewing Del iverables*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20041004.0004

170701 AP-12.1Q, Rev. 0, ICN 3. *Control of Measuring and Test Equipment*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040429.0006.

169649 AP-16.1Q, Rev. 7, ICN 3. Condition Reporting and Resolution. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040512.0003.

172198 AP-17.1Q, Rev. 3, ICN 3. *Records Management.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040915.0009.

172108 AP-2.27Q, Rev. 1, ICN 5. *Planning for Science Activities*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20041014.0001.

168667 AP-5.2Q, Rev. 1 ICN 0. *Testing Work Implementation and Control.* Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030206.0003.

167728 AP-EM-010, Rev. 0, ICN 2. *Environmental Baseline Review*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030730.0001.

165688 AP-SIII.1Q, Rev. 2, ICN 0. *Scientific Notebooks*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20021202.0026.

168062 AP-SIII.3Q, Rev. 2, ICN 1. *Submittal and Incorporation of Data to the Technical Data Management System.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040226.0001.

159295 AP-SIII.7Q, Rev. 0, ICN 1. *Scientific Investigation Laboratory and Field Testing.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020701.0180.

168938 AP-SV.1Q, Rev. 1, ICN 1. *Control of the Electronic Management of Information*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040308.0001.

170142 ASTM D 6250-98 (Reapproved 2003). 2003. *Standard Practice for Derivation of Decision Point and Confidence Limit for Statistical Testing of the Mean Concentration in Waste Management Decisions*. West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 256140.

170114 LP-2.13Q-OCRWM Rev. 0, ICN 0. *Verification of Education and Experience of Personnel.* Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20031112.0001.

170703 LP-2.23Q-BSC, Rev. 0, ICN 1. *Work Request/Work Order Process*. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040525.0002.

171737 LP-3.11Q-BSC Rev 0, ICN 1. *Technical Reports*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040915.0003.

170072 LP-ESH-019-BSC, Rev. 1, ICN 3. *Silica Protection.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040603.0002.

170704 LP-OM-070-BSC, Rev. 0, ICN 1. *Site Access Control.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040331.0008.

158528 LP-SA-001Q-BSC, Rev. 0. *Determination of Importance and Site Performance Protection Evaluations*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020510.0386.

172199 LP-SMF-002Q-BSC, Rev. 2, ICN 0. *Field Logging, Handling, and Documenting Borehole Samples.* Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040907.0003.

170193 QAP-2-6, Rev. 4, ICN 1. *Readiness Review*. Las Vegas, Nevada: CRWMS M&O. ACC: DOC.20030902.0006.

7.3 DATA, LISTED BY DATA TRACKING NUMBER

147613 GS000308311221.005. Net Infiltration Modeling Results for 3 Climate Scenarios for FY99. Submittal date: 03/01/2000.

148605 SN0002T0872799.007. Thermal-Hydrologic-Chemical (THC) and Thermal-Hydrologic (TH) -Only Drift-Scale Model Analysis. Submittal date: 02/01/2000.

INTENTIONALLY LEFT BLANK

APPENDIX A

GLOSSARY

APPENDIX A

GLOSSARY

accessible environment–Any point outside of the controlled area, including (1) atmosphere (including the atmosphere above the surface area of the controlled area), (2) land surfaces, (3) surface waters, (4) oceans, and (5) lithosphere.

accuracy–The degree to which a calculation, measurement, or set of measurements agree with a true value or an accepted reference value.

Alloy 22–A high-nickel alloy used for the outer barrier of a waste package.

barrier–Any material, structure, or feature that, for a period to be determined by NRC, prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste. For example, a barrier may be a geologic feature, an engineered structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around the waste, provided that the material substantially delays movement of water or radionuclides.

baseline–A set of information (developed from site characterization data, modeling assumptions or results, design bases and specifications, other relevant analogue or technical information) and analysis of that information on those parameters selected to be monitored, tested, evaluated, or observed during the performance confirmation program. The baseline is the standard to which comparisons are made, by parameter, to evaluate performance confirmation data. For the performance confirmation plan purposes, the baseline includes expected range, condition limits, and trend indicators (see baseline condition).

baseline condition–A set of critical observations or data used for comparison or a control. When hypothesis testing is applied to performance confirmation decisions, data are used to choose between a presumed baseline condition and an alternative condition. Baseline conditions are also referred to as the baseline for statistical comparisons. Deviations from the baseline do not necessarily impact performance, only where the trend is unexpected or they exceed a predetermined decision point (action level) based on performance assessment sensitivity analysis.

cladding–The metallic outer sheath of a fuel element generally made of stainless steel or a zirconium alloy. It is intended to isolate the fuel element from the external environment.

colloid–A large molecule or small particle that has at least one dimension within the size range of 10^{-9} to 10^{-6} meter, and is suspended in a liquid such as groundwater.

condition limit–The discrete value(s) or trend(s) outside (upper or lower) the expected range that results in more detailed evaluation and potentially additional sampling (including adversely developing trends as defined in the PC Test Plans). The exceedance of a condition limit may cause a decision-maker to choose one of the alternative actions (e.g., conclusion of compliance or noncompliance). The condition limit is defined during the planning phase of a data collection activity (based on that parameter's importance to performance); it is not calculated from the sampling data. Condition limits for parameters will be discussed in the PC Test Plan for that activity.

confirmation, or to confirm–In the context of the performance confirmation program, means to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes.

corrosion coupon–Synonymous with test sample in corrosion testing investigations where samples are selected to be representative of the waste package and drip shield materials, including processes used to fabricate, assemble, weld, and stress relieve these materials.

decision rule–A set of directions in the form of a conditional statement that specify the following: (1) how the sample data will be compared to the condition limit, (2) which decision will be made as a result of that comparison, and (3) what subsequent action will be taken based on decisions.

design bases–Information that identifies the specific functions to be performed by items and the specific values or ranges of values chosen for controlling parameters as reference bounds for design.

disposal–The emplacement of radioactive waste in a geologic repository with the intent of leaving it there permanently.

dose–The total effective dose equivalent means, for purposes of assessing doses to workers, the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). For purposes of assessing doses to members of the public, total effective dose equivalent means the sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

drift–The near-horizontal underground excavations from the shaft(s) or ramp(s) to the other excavations such as alcoves and rooms. The term includes excavations for emplacement (emplacement drifts) and access (access mains).

drip shield–A component of the Engineered Barrier System. The drip shield is above the waste package and is designed to (1) prevent seepage from dripping directly onto the surface of the waste package, and (2) to mitigate the effects of rockfall.

emplacement–The placement and positioning of spent nuclear fuel or high-level radioactive fuel (i.e., waste packages) in prepared locations within excavations of a geologic repository.

emplacement drift–A drift in which waste packages are placed.

Engineered Barrier System–The waste packages, including engineered components and systems other than the waste package (e.g., drip shields), and the underground facility.

experiment–A test under controlled conditions.

Exploratory Studies Facility–An underground facility at Yucca Mountain used for performing site characterization studies. The facility includes a 7.9-km (4.9-mi) main loop (tunnel), the 2.8-km (1.7-mi) Enhanced Characterization of the Repository Block Cross-Drift, and a number of alcoves used for site characterization tests such as the Drift Scale Test.

feature–A natural barrier structure, characteristic, process or condition that functions to prevent or reduce the movement of water or prevent the release or substantially reduce the release rate of radionuclides.

geologic repository–A system that is intended to be used for, or may be used for, the disposal of radioactive waste in excavated geologic media. A geologic repository includes the geologic repository operations area, and the portion of the geologic setting that provides isolation of the radioactive waste.

geologic repository operations area–A high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas, where waste handling activities are conducted.

geologic setting–The geologic, hydrologic, and geochemical systems of the region in which a geologic repository is or may be located.

hydraulic conductivity–A measure of the ability to transmit water through a permeable medium.

host rock–(1) The rock unit in which the potential repository would be located. For a repository at Yucca Mountain, the host rock would be the middle portion of the Topopah Spring Tuff of the Paintbrush Group. (2) The geologic medium in which the waste is emplaced.

in situ–In its natural position or place. The phrase distinguishes between tests or experiments conducted in the field (e.g., in an underground excavation, in-place) from tests and experiments conducted in a laboratory.

lithophysal–Pertaining to tuff units with lithophysae, small, bubble-like holes in the rock caused by volcanic gases trapped in the rock matrix as the ash-flow tuff cooled, often having concentric shells of finely crystalline alkali feldspar, quartz, and other materials that were formed by the entrapped gases that later escaped.

model–A representation of a system, process, or phenomenon, along with hypotheses required to describe the process or system or to explain the phenomenon, often mathematically. Model development typically progresses from conceptual models to mathematical models.

monitoring–To keep track of systematically with a view to collecting information and to analyze or sample, especially on a regular or ongoing basis. In performance confirmation, monitoring is generally long-term observation or sampling for a parameter or set of parameters.

near-field–The region where the natural barrier may be significantly perturbed by repository excavation and the emplacement of waste.

negligible–So small, unimportant, or of so little consequence as to warrant little or no attention.

observation drift–A drift near a thermally accelerated emplacement drift, from which conditions in the observed drifts can be monitored without adverse effects from radiation or temperature and with minimal disruption of the conditions in the observed drift.

parameter–Scientific data, performance assessment data, or engineering technical information that represent physical or chemical properties, consisting of an assigned variable name and generally represented by a value or range of values. Select parameters that potentially are subject to varied interpretation and selection of multiple values, and subject to multiple use for various technical products within the Project, reside in the Technical Data Management System (see observation and sample).

passive film–A stable impervious oxide film which makes a metal or alloy resistant to further "oxidation" or rusting. The basic resistance to corrosion of some metals and alloys occurs because of their ability to form a protective coating on the metal surface. The chromium in Alloy 22 combines with oxygen in the atmosphere to form a thin, invisible layer of chrome-containing oxide, called the "passive film." The film self-repairs in the presence of oxygen if the Alloy 22 is damaged mechanically or chemically, and thus prevents corrosion from occurring.

performance assessment–An analysis that: (1) identifies the features, events, processes (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the Yucca Mountain disposal system and their probabilities of occurring during 10,000 years after disposal; (2) examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the Yucca Mountain disposal system; and (3) estimates the annual dose incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence.

performance confirmation–The program of tests, experiments, and analyses conducted to evaluate the accuracy and adequacy of the information used to demonstrate compliance with the postclosure performance objectives in Subpart E of 10 CFR Part 63.

Performance Confirmation Test Plan (PC Test Plan)–A test plan specifically developed to support the tests, experiments, and analyses of the performance confirmation program. PC Test Plans are distinct from other types of test plans that will be generated for planning and executing tests that are used to verify conformance of an item to specified requirements, or to demonstrate satisfactory performance for service. Examples of such preclosure testing include prototype qualification tests, production tests, proof tests prior to installation, construction tests, and preoperational tests.

permanent closure–Final backfilling of the underground facility, if appropriate, and the sealing of shafts, ramps, and boreholes.

permeability–In general terms, the capacity of a medium (like rock, sediment, or soil) to transmit liquid or gas.

population (statistical)–In statistics, the total collection of objects or events, or universe of a defined class of natural or constructed conditions to be studied and from which a sample is to be drawn. The set of data that consists of all possible observations or values of a certain phenomenon. In the context of analysis of performance confirmation, the population does not refer to people.

precision–A measure of mutual agreement among individual measurements of the same property.

process model–A mathematical model that represents an event, phenomenon, process, component, etc., or series of events, phenomena, processes, or components, etc. A process model may undergo an abstraction for incorporation into a system model.

retrieval–The act of permanently removing radioactive waste from the underground location at which the waste had previously emplaced for disposal.

risk-informed, performance-based–An approach to decision-making whereby risk insights are considered together with other factors to establish requirements that better focus attention on design, operation, and performance issues commensurate with their importance to public heath and safety.

sample (statistical)–In statistics, a set of data from the population.

saturated zone–That part of the earth's crust beneath the regional water in which voids, large and small, are filled with water under pressure greater than atmospheric.

seepage–The flow of the groundwater in fractures or pore spaces of permeable rock to an open space in the rock; the percolation flux that enters an underground opening.

seismic–Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.

seismic event–An earthquake.

sensitivity study–An analytic or numerical technique for examining the effects of varying specified parameters in a computer model. Shows the effects that changes in various parameters have on model outcomes and illustrates which parameters have a greater impact on the predicted behavior of the system being modeled. Also called *sensitivity analysis* because it shows the sensitivity of the consequences (e.g., radionuclide release) to uncertain parameters (e.g., the infiltration rate that results from precipitation).

significance–An effect is said to be significant if the value of the statistic used to test it lies outside defined limits, that is to say, if the hypothesis that the effect is not present is rejected. A test of significance is one that, by use of a test statistic, purports to provide a test of the hypothesis that the effect is absent. By extension, the critical values of the statistics are themselves called significant (see statistical hypothesis).

site–That area surrounding the geologic repository operations area for which DOE exercises authority over its use in accordance with the provisions of 10 CFR Part 63.

site characterization–The program of exploration and research, both in the laboratory and in the field, that is undertaken to establish the geologic conditions and the ranges of parameters of a particular site that are relevant to the implementing documents.

statistical hypothesis–In statistics, a hypothesis concerning the parameters or form of the probability distribution for a designated population or populations, or, more generally, of a probabilistic mechanism which is supposed to generate the observations. Hypothesis testing is a term used generally to refer to testing significance when specific alternatives to the null hypothesis are considered. The null hypothesis is that assumed to be true, unless the data indicate with sufficient confidence that it should be rejected in favor of the alternative hypothesis. The alternative hypothesis is accepted if the null hypothesis is rejected by statistical tests (see significance and population, statistical).

total system performance assessment–A risk assessment that quantitatively estimates how the proposed Yucca Mountain repository system performs in the future under the influence of specific features, events, and processes, incorporating uncertainty in the models and data. Its purposes are: (1) provide the basis for predicting system behavior and for testing that behavior against safety measures in the form of regulatory standards, (2) provide the results of total system performance assessment analyses and sensitivity studies, (3) provide guidance to site characterization and repository design activities, and (4) help prioritize testing and selection of the most effective design options.

trend–A long-term movement in an ordered series, which may be regarded, together with the oscillation and random component, as generating the observed values.

tuff–Igneous rock formed from compacted volcanic fragments created from pyroclastic (explosively ejected) flows with particles generally smaller than 4 mm in diameter; the most abundant type of rock at the Yucca Mountain site.

uncertainty–A quantitative or qualitative measure of how well a mathematical model represents a system, process, or phenomenon; or the interval above and below the measurement, parameter, or result that contains the true value. There are two types of uncertainty: (1) Stochastic (or aleatory) uncertainty caused by the random variability in a process or phenomenon (2) State-of-knowledge (or epistemic) uncertainty, which results from a lack of complete information about physical phenomena. State-of-knowledge uncertainty is further divided into: (i) Parameter uncertainty, which results from imperfect knowledge about the inputs to analytical models (ii) Model uncertainty, which is caused by imperfect models of physical systems, resulting from simplifying assumptions or an incomplete identification of the system modeled (iii) Completeness uncertainty, which refers to the uncertainty as to whether the important physical phenomena, relationships (coupling), and events have been considered.

underground facility–The underground structure, backfill materials, if any, and openings that penetrate the underground structure (e.g., ramps, shafts, and boreholes, including their seals).

unsaturated zone–The zone between the land surface and the regional water table. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the fluid pressure locally may be greater than atmospheric.

variability–Refers to the observed difference attributed to heterogeneity or diversity in a population. Sources of variability are the results of natural random processes and stem from the differences among the elements of a population. Variability is not usually reducible by further measurement but can be better estimated by increased sampling based on the understood or assumed distribution in the parameter's physical attributes.

variance–In performance confirmation, a difference between what is expected or predicted and what actually occurs. In statistics, the total variation displayed by a set of observations, as measured by the sums of squares of deviations from the mean, may in certain circumstances be separated into components associated with defined sources of variation used as criteria of classification for the observations. Such an analysis is called an analysis of variance, although in the strict sense it is an analysis of sums of squares. Many standard situations can be reduced to the variance analysis form.

waste form–The radioactive waste materials and any encapsulating matrix.

waste package–The waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

INTENTIONALLY LEFT BLANK

Addendum Cover Page

Complete only applicable items.

QA: QA

1. Total Pages: 78

2. Addendum to (Title): Performance Confirmation Plan			
3. DI (including Revision and Addendum No.): TDR-PCS-SE-000001 REV 05 AD 01			
	Printed Name	Signature	Date
4. Originator	for F.D. Hansen Carol Hause	Carol Hause	2-25-08
5. Checker	Jeff Gromny	Jeff Gromny	2-25-08
6. QCS / QA Reviewer	Charles Beach	Charles D. Beach	2-25-08
7. Responsible Manager / Lead	F.D. Hansen	FD Hansen	2-25-08
8. Responsible Manager	M.K. Knowles	MK Knowles	2/25/08
9. Remarks			

Change History

10. Revision and Addendum No.	11. Description of Change
REV 05 AD 01	Initial Issue.

SUMMARY AND ORGANIZATION

This addendum to Revision 05 of *Performance Confirmation Plan* (PC Plan) (BSC 2004 [DIRS 172452]) is created for four primary purposes:

1. To emphasize that individual performance confirmation (PC) test plans contain detailed implementation information. The purpose of the PC Plan is to provide a higher-level planning document that identifies activities, intended scope, and candidate parameters.

2. To illustrate the process for developing the PC test plans. The process requires cross-disciplinary review as the test plan is being developed and allows for final approval of the test plan by the Office of Civilian Radioactive Waste Management.

3. To describe the methodology for selecting parameters and quantifying condition limits. Final selection of parameters and condition limits is documented in the individual PC test plans.

4. To document a completeness review of existing performance confirmation activities as detailed in Appendix A[a].

The PC Plan is expected to be updated periodically. These revisions or addenda are intended to ensure consistency between the plans for confirmation and the information used in the Safety Analysis Report (SAR). Technical documents such as the postclosure nuclear safety design basis (PoNSDB) and the total system performance assessment (TSPA) documents were used for this addendum to assess performance confirmation activities for relevance.

The organization of this addendum corresponds to the major outline of the parent report and includes all sections mandated by the governing procedure (LS-PRO-001), regardless of whether or not a mandated section is being modified. Mandated sections, in other words, are reproduced in this addendum for procedural compliance and convenience of cross-referencing, but may not contain actual modifications to the parent report. In such cases, the addendum section contains a bracketed statement of “No modification” under the section heading.

Conversely, sections not mandated by procedure (i.e., most subsections) are reproduced in this addendum only if they contain a modification to the corresponding section of the parent report, which is also true of any other addendum elements (i.e., figures, tables, equations, or appendices). Unless added as new elements not present in the parent report, the numbering of addendum elements such as figures, tables, equations, and appendices corresponds to the numbering in the parent report. Bracketed designators (e.g., “[a]”) are added to all numbered elements in this addendum to distinguish them from corresponding elements in the parent report.

In every case, the modifications presented in this addendum are preceded by bracketed, italicized text explaining why the modification was made and how it relates to the corresponding element in the parent report. When appropriate, this explanatory text may cite page and paragraph numbers from the parent report for cross-referencing purposes.

INTENTIONALLY LEFT BLANK

CONTENTS

Page

INTENTIONALLY LEFT BLANK

FIGURES

Page

TABLES

Page

INTENTIONALLY LEFT BLANK

ACRONYMS

[Acronyms and abbreviations used in this addendum are listed and defined below. Certain acronyms are used but not defined in the addendum text itself in order to reflect the treatment of acronyms in the parent report.]

BDCF	biosphere dose conversion factor
CDSP	codisposal (waste package)
CSNF	commercial spent nuclear fuel
DHLW	defense high-level waste
DOE	U.S. Department of Energy
DSNF	defense spent nuclear fuel
EBS	engineered barrier system
FEPs	features, events and processes
HLWG	high-level waste glass
ITBC	important to barrier capability
ITWI	important to waste isolation
LNB	lower natural barrier
NRC	U.S. Nuclear Regulatory Commission
OCB	outer corrosion barrier
OCS	Office of the Chief Scientist
PC	performance confirmation
RMEI	reasonably maximally exposed individual
SAR	Safety Analysis Report
SCC	stress corrosion cracking
SMEs	subject matter experts
SNF	spent nuclear fuel
SRRC	standard rank regression coefficient
SZ	saturated zone
TAD	transportation, aging, and disposal (canister)
TH	thermal hydrological
TSPA	total system performance assessment
UNB	upper natural barrier
UZ	unsaturated zone

INTENTIONALLY LEFT BLANK

1[a]. INTRODUCTION

[No modification to parent report.]

2[a]. REQUIREMENTS AND GUIDANCE

[No modification to parent report.]

3[a]. DESCRIPTION OF PERFORMANCE CONFIRMATION ACTIVITIES

[The following sections are added after Section 3.4 of the parent report. This additional information evaluates aspects of the performance confirmation planned program against new results from TSPA and new analysis of barrier capability. In addition, the plan is modified to address new design information on sealing of shafts, ramps, and boreholes.]

3.5[a]. ADDITIONAL ANALYSIS OF PERFORMANCE CONFIRMATION ACTIVITIES

3.5.1[a]. Content of Performance Confirmation Test Plans

The decision analysis process resulting in the PC activities is based on the most current technical information available. Results of the decision analysis are assessed periodically to ensure that the activities intended for performance confirmation continue to be relevant.

Parameters and methods considered in the PC Plan (BSC 2004 [DIRS 172452]) are sometimes conceptual in nature, as is common when considering future work. As the PC test plans are developed, the rigor necessary for planning the details of the activity and developing the expected limits and condition limits may result in the need to make some changes to the activity as described in the PC Plan. Thus, anticipated methodology may deviate from the exact wording in the PC Plan. Development of the PC test plans results in a more mature and realistic description of the PC activity, which is appropriate and expected during the detailed planning stage of the PC activity. Justifications for deviations from the PC Plan (BSC 2004 [DIRS 172452]) are documented in the PC test plans, when appropriate. This distinction between the PC Plan and the PC test plans is necessary to ensure flexibility when testing and monitoring details are finalized in the PC test plans.

The PC Plan (BSC 2004 [DIRS 172452]) includes twenty activities selected from a performance-based risk-informed process. Each of the twenty activities includes multiple parameters and monitoring options. The performance confirmation program periodically updates the PC Plan to ensure that the information therein is consistent with the license baseline information and reflects the most current understanding of the postclosure safety analysis. Confirmation activities may be reevaluated during the licensing phase, specifically as requested during review by the U.S. Nuclear Regulatory Commission (NRC). Proposed PC scope changes are carefully examined using the requirements in 10 CFR 63.44 [DIRS 180319]. Also, it is verified that the reporting processes developed for performance confirmation are consistent with reporting conditions of construction permits in 10 CFR 50.55 [DIRS 181964].

The performance confirmation program is conducted to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Revisions and updates to the PC Plan (BSC 2004 [DIRS 172452]) are expected and necessary. The reasons for changing the PC Plan may include a better understanding of the performance assessment models with respect to barrier performance, improved understanding of details of features and processes with respect to barrier capability, and possible design changes or programmatic decisions. Its implementation supports the technical building blocks of the performance assessment. Testing and monitoring details for performance confirmation are delineated in individual PC test plans, in which parameters, ranges, and condition limits are quantified. The activities described in the existing PC Plan, which represents the performance confirmation baseline for the license application, are comprehensive in scope but not yet all defined in detail. Specific PC activities will be further defined as additional PC test plans are developed after license application submittal.

Many of the twenty activities included in the PC Plan (BSC 2004 [DIRS 172452]) represent generalized processes and methodologies, and all of the activities can be implemented in a number of ways. Some PC activities are described in detail in the PC Plan, while others are conceptual and require additional consideration as the PC test plans are developed. The descriptions of the activities in the PC Plan provide the expected starting point and anticipated methodologies. There is no intended requirement regarding performance confirmation methodologies set by the language in the PC Plan. The candidate parameters, test concepts, and implementation technologies developed for the PC Plan remain preliminary until they are formalized in the more-detailed PC test plans. For example, other technologies may be located that could allow for direct measurement of a parameter that previously had been derived from surrogates or other parameters. This addendum ensures flexibility for implementation of requisite details in the individual PC test plans. The following is an example implementation that is necessary for the PC test plan for precipitation monitoring.

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 to 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. The precipitation monitoring activity as described in the PC Plan includes analysis of precipitation composition; however, the chemical analysis of precipitation was not carried forward in the details of the PC test plan (SNL 2007 [DIRS 183950]) for the following reason. PC test plans are intended to test and/or confirm the adequacy of assumptions, data, and analyses that are used as the licensing basis to support a permit for construction authorization. The chemical composition of precipitation is not an input to the infiltration or unsaturated zone flow models used to support the licensing case. In addition, there is a sparse baseline for the composition of precipitation specifically at Yucca Mountain. The chemistry of precipitation from regional surrogate stations serves well to characterize the baseline for Yucca Mountain. Precipitation chemistry parameters cannot be compared to the licensing basis and, therefore, are not carried forward into the confirmation activity.

3.5.2[a]. Process for Development of the PC Test Plans

Development of PC test plans follows quality assurance procedure SCI-PRO-002, *Planning for Science Activities*. Testing and monitoring activities that are identified and undertaken for the purpose of performance confirmation include the information required by SCI-PRO-002, as well as the following information as required by regulation:

- The planning documents for performance confirmation include "Performance Confirmation Test Plan" in their title.[1]
- Each PC test plan describes the relevance of the activity to performance assessment, if appropriate.
- The PC test plan describes the regulatory requirement, if appropriate.
- The PC test plan describes observations, measurements, and expected data quality objectives.
- The PC test plan describes the process for reporting unexpected results or conditions.

Further details on the contents of the PC test plans are provided in Section 5 of the parent report.

Two key aspects of a successful PC program are: (1) the selection of the parameters to be measured or monitored, and (2) the determination of the conditions for which the NRC will be notified regarding measured and monitored information that differs from the technical baseline. Condition limits[2] are set for confirmation parameters being monitored. When these condition limits are exceeded, the PC program is obligated to report to the U.S. Department of Energy (DOE), which will notify the NRC, as discussed in the main text of the PC Plan and recapitulated in the PC test plans. There may be parameters that do not have the condition limits because the performance assessment is structured to cover a very broad range of values. In these cases, the parameters are collected to evaluate trends or to support other PC activities.

The PC Plan (BSC 2004 [DIRS 172452]) documents the overall strategy for implementing the performance confirmation program. It identifies and describes the development of a list of performance confirmation activities as well as candidate parameters for each activity. Specific information regarding a particular performance confirmation activity—the actual selection of parameters based on the candidates identified in the PC Plan (BSC 2004 [DIRS 172452]), the setting of condition limits, and details of the testing and data acquisition methods—are documented in PC test plans.

[1] The exception to this is the construction effects monitoring test plan (BSC 2006 [DIRS 177845]), which was the first PC test plan to be developed and which was completed before the SCI-PRO-002 requirements went into effect.

[2] A condition limit defines the magnitude of differences between PC monitoring and testing results and the license application technical basis that are significant enough to enter into the Corrective Action Program and report to the Office of Civilian Radioactive Waste Management.

Justification is provided when a PC test plan deviates from the descriptions in the PC Plan (BSC 2004 [DIRS 172452]). Confirmation activities may change during the licensing process, perhaps in response to feedback from the NRC during the licensing review. Proposed PC scope changes are carefully examined and vetted against the requirements in 10 CFR 63.44 [DIRS 180319]. The reporting processes developed for performance confirmation are consistent with reporting conditions of construction permits in 10 CFR 50.55 [DIRS 181964] and 10 CFR 21 [DIRS 176626].

3.5.3[a]. Selection of Parameters and Condition Limits

It is anticipated that the list of performance confirmation activities and associated candidate parameters is reviewed and updated as necessary. New information includes results of sensitivity studies. For example, in each of the three specific PC test plans that have already been prepared based on the information contained in the PC Plan, parameters are selected and quantified in terms of expected ranges and condition limits. The circumstances of each testing and monitoring activity dictate unique treatment of the parameter ranges and limits.[3] The PC test plans identify one or more parameters to be monitored for a particular activity as well as the associated monitoring, testing, and data collection, including the methods for analyzing and evaluating this information (the process described in the PC Plan (BSC 2004 [DIRS 172452], Figure 4-1) will be followed). They also establish bounds for parameters, condition limits, the basis for the limits, and required actions if these limits are exceeded. The condition limits are set below the point at which the models predict reduction in barrier or total system capability. The parameter-selection efforts incorporates, as applicable, results from a risk-informed knowledge base that includes the analysis/model reports, the technical data input packages, the TSPA compliance model, and ongoing sensitivity and uncertainty analyses. The parameter-selection process utilizes the experience and insights possessed by subject matter experts (SMEs), from both the process modeling and TSPA. Activities and parameters associated with the waste retrievability requirement from Section 1.4.3 of the PC Plan (BSC 2004 [DIRS 172452]) are evaluated for their importance to meeting that requirement, in conjunction with the appropriate design and engineering teams.

The TSPA simulations provide the basis for the compliance analysis presented in the license application. Other specially designed impact and sensitivity analyses augment the risk-informed knowledge base detailed in the PC Plan (BSC 2004 [DIRS 172452]) for evaluating performance confirmation parameters. In addition, targeted impact analyses (i.e., analyses that change a selected aspect of repository performance to quantify the impact that aspect has on total system performance) are also conducted to determine objectively which activities and parameters are most important to each barrier's performance as well as to total system performance.

Once parameters are selected, expected ranges, condition limits, and other related information are developed using the risk-informed knowledge base, and documented in the PC test plans. The SMEs develops expected ranges to capture the input set provided to the TSPA, as documented in analysis/model reports and technical data input packages. The expected ranges are developed considering: (1) allowance for natural or measurement-related variability,

[3] Some of the PC Plan activities are regulatory requirements and are not derived from the TSPA, such as specific requirements for retrievability, mapping, and seal-testing.

(2) expectations of the technical measurements (data quality objectives), (3) performance assessment results that remain acceptable for values within the limits, and (4) maintenance of substantial margins between condition limits and values representing design criteria, or significantly influencing determinations of barrier functionality or compliance with performance objectives. In practice, the expected range is often a design basis or the range from model realizations. The condition limits are based on the performance assessment model validity conditions, how important the parameter is to performance and barrier capability, the results of uncertainty and sensitivity analyses, and evaluation of available data.

3.5.4[a]. Completeness Review Analysis Results

A completeness review has been performed comparing the activities to the representation of key features and processes in the performance assessment models; the review is documented in Appendix A[a] of this addendum. Performance confirmation activities were also matched with the technical bases for multiple barrier capability and the characteristics of the barriers that are deemed important to barrier capability. This exercise confirmed that the existing performance confirmation activities provide a breadth of investigations sufficient to evaluate the performance basis of the license application. A synopsis of the process and results is given here and the detailed evaluations are described in Appendix A[a].

The current PC Plan (BSC 2004 [DIRS 172452]) is based on an in-process understanding of performance assessment and barrier capability developed and published before completing the total system performance assessment for the license application (TSPA-LA) (SNL 2008 [DIRS 183478]). Appendix A[a] of this addendum is a record of the findings of the comparisons between the TSPA, the PoNSDB document (SNL 2008 [DIRS 177464]), and the content of the PC Plan. These three documents are referenced frequently in Appendix A[a] by their respective abbreviated titles (e.g., TSPA, PoNSDB, and PC Plan). The TSPA provides information on parameters important to risk and dose. The TSPA comprises performance assessment models for which many of the most important parameters are identified. Similarly, the PoNSDB identifies core parameter characteristics for features/components important to barrier capability. The models, the most significant model parameters, and the core parameter characteristics of the barrier capability are all related to performance confirmation activities by the conduct of this exercise.

The PC Plan (BSC 2004 [DIRS 172452]) and detailed PC test plans describe a testing and monitoring program that is intended to confirm information used to develop the safety case, including the postclosure technical baseline and performance assessment. Models and submodels developed for the included features, events, and processes (FEPs) are implemented in the TSPA to provide risk-informed, performance-based analyses. The PoNSDB also uses FEPs to determine importance to barrier capability. The PoNSDB selects and documents control and core parameter characteristics. Core parameter characteristics deemed important to barrier capability and which are possible to test or monitor would be candidates for inclusion in the confirmation program. Some aspects of barrier capability identified in the PoNSDB are not included in performance assessment models, but are compared to the PC Plan activities. Thus, the PC Program assesses the risk-informed, performance-based nature of the process-level understanding, as well as those processes captured in the TSPA. Also, the PoNSDB identifies all barrier capabilities, whereas TSPA identifies which of these capabilities are represented in risk and performance determinations.

Technical reviews and discussions involved representatives from Lead Lab's Performance Assessment System Integration and Performance Confirmation staff, as well as DOE's Office of the Chief Scientist (OCS). Subject matter experts assessed the relationships between the current version of the TSPA (i.e., the basis of the safety case of the license application), the performance assessment models supporting the TSPA, and the 20 activities identified in the PC Plan. In addition, this group included authors of the PoNSDB to ensure consistency between features that were designated as important to barrier capability and testing and monitoring activities within the PC Plan.

3.5.5[a]. Modification of the Plan for Testing of Backfill and Plugs Used for Sealing

The seals testing activity in the parent report (Section 3.3.3.1) is revisited here to reflect design changes. The repository design basis has been changed so that sealing of shafts and ramps will be accomplished by backfilling (BSC 2008 [DIRS 183627], Parameter 09-01), and sealing of boreholes will be accomplished by backfilling and plugging (BSC 2008 [DIRS 183627], Parameter 90-03). 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 [DIRS 180319]), and in accordance with the design changes, drift stability, water intrusion, and magma flow between drifts are not important considerations.

The purpose for the performance confirmation seals testing activity has changed, to evaluate design assumptions for implementation of backfilling and plugging measures to effect permanent repository closure. Closure of shafts, ramps, and boreholes by these measures has been determined not to be important to barrier capability (SNL 2008 [DIRS 177464], Appendix A) and is therefore not included among the features evaluated in the completeness analysis of Appendix A[a] to this addendum. Notwithstanding these changes, the associated confirmatory testing activity remains relevant to performance confirmation and 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 shafts and ramps, and backfilling and plugging of boreholes, 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.

3.5.6[a]. Conclusions

This exercise demonstrates that the performance confirmation plan remains relevant to the license application bases, including the TSPA (risk significance) and PoNSDB (barrier capability). The evaluation affirms that the PC Plan activities 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 TSPA sensitivity information provided in Appendix A[a] shows that the most risk-significant TSPA parameters are informed by performance confirmation activities. From the completeness review documented in Appendix A[a], it is concluded that the planned performance confirmation activities, as defined in the parent report, are sufficient to address the features and characteristics that describe barrier capability. The PC Plan is expected to be revised again in the future to reflect developments in support for the safety case. The PC test plans contain the detailed identification and evaluation of parameters, bounds, and condition ranges, as demonstrated by the completed and available examples of those plans.

4[a]. DATA MANAGEMENT, ANALYSIS, AND REPORTING

[No modification to parent report.]

5[a]. TEST PLANNING AND IMPLEMENTATION

[No modification to parent report.]

6[a]. SCHEDULE

[No modification to parent report.]

7[a]. REFERENCES

7.1[a]. DOCUMENTS CITED

[The following reference listings pertain only to their use in this addendum.]

170035 BSC (Bechtel SAIC Company) 2004. *Conceptual Model and Numerical Approaches for Unsaturated Zone Flow and Transport.* MDL-NBS-HS-000005 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040922.0006; DOC.20050307.0009.

169987 BSC 2004. *CSNF Waste Form Degradation: Summary Abstraction.* ANL-EBS-MD-000015 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040908.0001; DOC.20050620.0004.

166107 BSC 2004. *Drift Degradation Analysis.* ANL-EBS-MD-000027 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040915.0010; DOC.20050419.0001; DOC.20051130.0002; DOC.20060731.0005.

172452 BSC 2004. *Performance Confirmation Plan.* TDR-PCS-SE-000001 REV 05. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041122.0002.

171764 BSC 2004. *Seepage Calibration Model and Seepage Testing Data.* MDL-NBS-HS-000004 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040922.0003; DOC.20051121.0012.

177845 BSC 2006. *Technical Work Plan for: Construction Effects Monitoring.* TWP-MGR-GE-000006 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20060915.0004.

183627 BSC 2008. *Postclosure Modeling and Analyses Design Parameters.* TDR-MGR-MD-000037 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080108.0002.

101836 ICRP (International Commission on Radiological Protection) 1991. "1990 Recommendations of the International Commission on Radiological Protection." Volume 21, No. 1-3 of *Annals of the ICRP*. ICRP Publication 60. New York, New York: Pergamon Press. TIC: 235864.

181244 SNL (Sandia National Laboratories) 2007. *Abstraction of Drift Seepage.* MDL-NBS-HS-000019 REV 01 ADD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070807.0001.

177399 SNL 2007. *Biosphere Model Report.* MDL-MGR-MD-000001 REV 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070830.0007.

177418 SNL 2007. *Dissolved Concentration Limits of Elements with Radioactive Isotopes.* ANL-WIS-MD-000010 REV 06. Las Vegas, Nevada: Sandia National Laboratory. ACC: DOC.20070918.0010.

177407 SNL 2007. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071004.0001.

177412 SNL 2007. *Engineered Barrier System: Physical and Chemical Environment.* ANL-EBS-MD-000033 REV 06. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070907.0003.

180778 SNL 2007. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 02 ADD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20060427.0002; DOC.20070807.0004; DOC.20071003.0019.

178519 SNL 2007. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier.* ANL-EBS-MD-000003 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070730.0003; DOC.20070807.0007.

181648 SNL 2007. *In-Drift Natural Convection and Condensation.* MDL-EBS-MD-000001 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20050330.0001; DOC.20051122.0005; DOC.20070907.0004.

180506 SNL 2007. *In-Package Chemistry Abstraction.* ANL-EBS-MD-000037 REV 04 ADD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070816.0004.

183950 SNL 2007. *Performance Confirmation Test Plan for Precipitation Monitoring.* TWP-MGR-MM-000002 REV 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071114.0008.

177396 SNL 2007. *Radionuclide Transport Models Under Ambient Conditions.* MDL-NBS-HS-000008 REV 02 ADD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20050823.0003; DOC.20070718.0003.

177391 SNL 2007. *Saturated Zone Site-Scale Flow Model.* MDL-NBS-HS-000011 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070626.0004; DOC.20071001.0013.

176828 SNL 2007. *Seismic Consequence Abstraction.* MDL-WIS-PA-000003 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070928.0011.

181953 SNL 2007. *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials.* ANL-EBS-MD-000005 REV 04. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070913.0001.

184614 SNL 2007. *UZ Flow Models and Submodels.* MDL-NBS-HS-000006 REV 03 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080108.0003; DOC.20080114.0001.

183041 SNL 2008. *Features, Events, and Processes for the Total System Performance Assessment: Analyses.* ANL-WIS-MD-000027 REV 00. Las Vegas, Nevada: Sandia National Laboratories.

184433 SNL 2008. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 03 AD 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080201.0003.

177464 SNL 2008. *Postclosure Nuclear Safety Design Bases.* ANL-WIS-MD-000024 REV 01. Las Vegas, Nevada: Sandia National Laboratories.

182145 SNL 2008. *Simulation of Net Infiltration for Present-Day and Potential Future Climates.* MDL-NBS-HS-000023 REV 01 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080201.0002.

183478 SNL 2008. *Total System Performance Assessment Model /Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories.

[The following reference listings pertain only to their use in this addendum.]

7.2[a]. CODES, STANDARDS, REGULATIONS, AND PROCEDURES

176626 10 CFR 21. 2006. Energy: Reporting of Defects and Noncompliance. Internet Accessible.

181964 10 CFR 50. 2007. Energy: Domestic Licensing of Production and Utilization Facilities. Internet Accessible.

180319 10 CFR 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Internet Accessible.

184076 40 CFR 197. 2006. Protection of Environment: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada. Internet Accessible.

178394 70 FR 53313. Implementation of a Dose Standard After 10,000 Years. Internet Accessible.

SCI-PRO-002, *Planning for Science Activities.*

APPENDIX A[a]

COMPLETENESS EVALUATION OF PERFORMANCE CONFIRMATION FOR LICENSE APPLICATION

A.1[a] SUMMARY

The performance confirmation (PC) program is conducted to evaluate the adequacy of assumptions, data, and analyses leading to the findings that permit construction of the repository and subsequent emplacement of the wastes. The program evaluates information used as input to models, or evaluates whether observed behavior is consistent with expected or modeled performance. Some measurements pertinent to performance confirmation are expected to require longer periods of monitoring during the preclosure period than others. The ongoing scope will continue to be reviewed, evaluated, and updated as needed to reflect new technical, programmatic, and regulatory information so that the performance confirmation program is consistent with the confirmation needs of the license application baseline information.

The current performance confirmation plan as documented in the *Performance Confirmation Plan* (PC Plan) (BSC 2004 [DIRS 172452]) is based on an in-process understanding of performance assessment and barrier capability developed and published before completing the total system performance assessment for the license application (TSPA-LA) (SNL 2008 [DIRS 183478]). The PC Plan, as with all components of the license application, must be as complete as possible in light of information that is reasonably available at the time of submittal. This appendix is a record of the findings of the comparisons between the total system performance assessment (TSPA), *Post Closure Nuclear Safety Design Bases* (PoNSDB) (SNL 2008 [DIRS 177464]), and the content of the PC Plan. These three documents are referenced frequently in this appendix by their respective abbreviated titles (e.g., TSPA, PoNSDB, and PC Plan). The TSPA provides information on parameters important to risk and dose. The TSPA comprises performance assessment models, in which many of the most important parameters are identified. Similarly, the PoNSDB identifies core parameter characteristics for feature/components important to barrier capability, which would be candidates for evaluation in the performance confirmation program. Core parameter characteristics pertain to features/components included in models supporting performance assessment as well as to features, events and processes (FEPs) that have been excluded. Performance confirmation activities will evaluate both excluded and included FEPs.

The PC Plan and detailed PC test plans describe a testing and monitoring program that is intended to confirm information used to develop the safety case, including the postclosure technical baseline and performance assessment. Models and submodels developed for the included FEPs are implemented in the TSPA to provide risk-informed, performance-based analyses. The PoNSDB also uses FEPs to determine importance to barrier capability. The PoNSDB selects and documents control and core parameter characteristics. Core parameter characteristics deemed important to barrier capability (ITBC) and which are possible to test or monitor would be candidates for inclusion in the confirmation program. Some aspects of barrier capability identified in the PoNSDB are not significant in (or in some instances, excluded from) performance assessment models, but are compared to the PC Plan activities. Thus, the PC Program assesses the risk-informed, performance-based nature of the process-level understanding, as well as those processes captured in the TSPA. Also, PoNSDB identifies all barrier capabilities, whereas TSPA identifies which of these capabilities are represented in risk and performance determinations. To complete the assessment recorded in this appendix, technical reviews and discussions were held, which involved representatives from Lead Lab’s Performance Assessment System Integration and Performance Confirmation organizations, as well as the Department of Energy's Office of the Chief Scientist (OCS). Subject matter experts (SMEs) assessed the relationships between the current version of the TSPA (i.e., the basis of the safety case of the 2008 license application), the performance assessment models supporting the TSPA, and the 20 activities identified in the PC Plan. In addition, this group included authors of the PoNSDB to ensure consistency between features that were designated as ITBC and testing and monitoring activities within the PC Plan.

The PC Plan activities are developed on the basis of the knowledge of performance assessment analysts. Subject matter experts developed the risk-informed performance-based selection of the performance confirmation activities. The current license application contains an updated TSPA, including some changes to the performance assessment models. This evaluation identified models, parameters, and barrier capabilities that are included in the scope of performance confirmation activities described in the PC Plan. Details for actual deployment of performance confirmation testing and monitoring activities are developed within the individual PC test plans. The evaluation described in this appendix ensures consistency between the activities described in the PC Plan and the content of the Safety Analysis Report (SAR).

The activities identified in the PC Plan have been compared to the assumptions, data, and information that comprise the performance assessment models and results of the TSPA and the PoNSDB. This exercise has confirmed that the existing performance confirmation activities provide a breadth of investigations sufficient to evaluate the performance basis of the license application. None of these activities is identified for deletion at this time.

A.2[a] PURPOSE

This appendix documents the comparison of the content of the license application compliance model, as documented in *Total System Performance Assessment for the License Application* (SNL 2008 [DIRS 183478]), associated subsystem analyses that support the TSPA, *Postclosure Nuclear Safety Design Bases* (SNL 2008 [DIRS 177464]), and *Performance Confirmation Plan* (BSC 2004 [DIRS 172452]). As such, this evaluation determines relevance of the performance confirmation activities and assures correlation and consistency in these documents, which are part of the license application baseline. The results also provide an opportunity to ensure that confirmation testing and monitoring activities are being planned for parameters relevant to risk and performance. The TSPA models and parameters are evaluated for their impact to performance and correlated to the associated performance confirmation activities. In turn, the PoNSDB identifies features and components important to barrier capability. The PoNSDB lists control parameter characteristics that can be compared to candidate parameters associated with performance confirmation activities. Thus, the completeness comparison made in this study illustrates where important risk- and performance-based parameters and core parameter characteristics associated with barrier capability are tested and monitored in the performance confirmation activities.

The PC Plan describes the U.S. Department of Energy (DOE) strategy to collect, evaluate, and report on data used to confirm the basis for estimates of repository performance and to preserve of the ability to retrieve spent nuclear fuel and high-level radioactive waste from the repository at Yucca Mountain, Nevada. Subpart F of 10 CFR Part 63 [DIRS 180319] includes a requirement that the repository performance confirmation program evaluate the adequacy of the assumptions, data, and analyses that are the basis for NRC findings on compliance with the relevant performance objectives. This includes evaluation of the information used to demonstrate that system and subsystem components are functioning as intended. This information may include data and assumptions used in model development or as input to model implementation, as well as evaluations of whether observed behavior is consistent with expected or modeled performance.

The current suite of 20 activities was selected by technical and subject matter experts using their knowledge of total system and subsystem (i.e., barrier) performance sensitivity to specific input, confidence in the current representation of the input, and accuracy of the proposed activity in quantifying the input. Selection of confirmation activities, which previously used results from the TSPA model for Site Recommendation, is affirmed, establishing accuracy with license application documents.

A.3[a] EVALUATION METHODOLOGY

This evaluation was performed by a group of individuals technically cognizant of performance assessment and performance confirmation activities, representing both Lead Lab technical staff and DOE personnel. The evaluation process made use of draft information in Appendix K of *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008 [DIRS 183478]), as well as scientific judgment and familiarity with the elements of the PC Plan, PoNSDB, and the models and submodels supporting the TSPA. Participants reviewed quantitative and qualitative evaluation criteria such that a determination of performance basis could be assigned to models, model inputs and outputs, and underlying parameters. Technical staff participating in this review included the primary authors of the TSPA sections for the license application, the authors of the performance confirmation section of the license application, and the authors of the PoNSDB, as well as other subject matter experts.

The process implemented for this review and evaluation is illustrated in Figure A-1[a]. The review group evaluated three technical areas: (1) performance assessment models, analyses, and parameters, (2) barrier characteristics, and (3) performance confirmation activities. A complete listing of the models used in TSPA was compiled, including the input parameters and the output parameters. Uncertain parameters for each model were ranked by level of importance based on sensitivity analysis of total expected dose to the reasonably maximally exposed individual (RMEI). Qualitative evaluations of model importance to dose were based on TSPA results for total expected dose to the RMEI and knowledge of the processes contributing to total expected dose. These qualitative evaluations are consistent with the decision analysis process described in Section 1.4.1 of the PC Plan (BSC 2004 [DIRS 172452]), which provided the bases for the selected performance confirmation activities. The models and parameters used in TSPA were compared to the activities and candidate parameters included in the PC Plan.

This review also considered the information compiled in the PoNSDB, which defines core parameter characteristics and provides a listing of FEPs. The PoNSDB (SNL 2008 [DIRS 177464], Section 6.1.2) is a document that identifies three barriers (upper natural barrier (UNB), engineered barrier system (EBS), lower natural barrier (LNB)) to address the requirements of 10 CFR Part 63 [DIRS 180319]. The PoNSDB also identifies the features of these barriers. The barrier features generally contribute to the barrier capability because they reduce flow or radionuclide release rate, or rate of radionuclide transport to the accessible environment. A few barrier characteristics contribute to barrier capability but are not implemented in the TSPA or its supporting body of analyses and models. The FEPs are discussed in the PoNSDB in terms of their effects on barrier capability. Thus, the PoNSDB differentiates between features/components that are ITBC and those that are not ITBC. Only the core parameter characteristics designated as ITBC for features/components related to barrier capability, as identified in the PoNSDB document (SNL 2008 [DIRS 177464], Appendix A), are candidates for performance confirmation testing and monitoring. For the ITBC core parameter characteristics as identified in the PoNSDB, a qualitative determination is made in this appendix as to whether that parameter characteristic will be addressed by an activity identified within the existing PC Plan.

This evaluation process allowed correlation between confirmation activities related to barrier features summarized in the PoNSDB and performance assessment parameters and models summarized in TSPA. The evaluation of the models and parameters and their associated confirmation activities are described in Section A-4[a]. The evaluation of the relationship between confirmation activities and the PoNSDB core parameter characteristics, which have been deemed ITBC, is covered in this appendix. The remainder of this appendix describes the evaluation process, qualitative determinations of importance, and the associated performance confirmation activities.

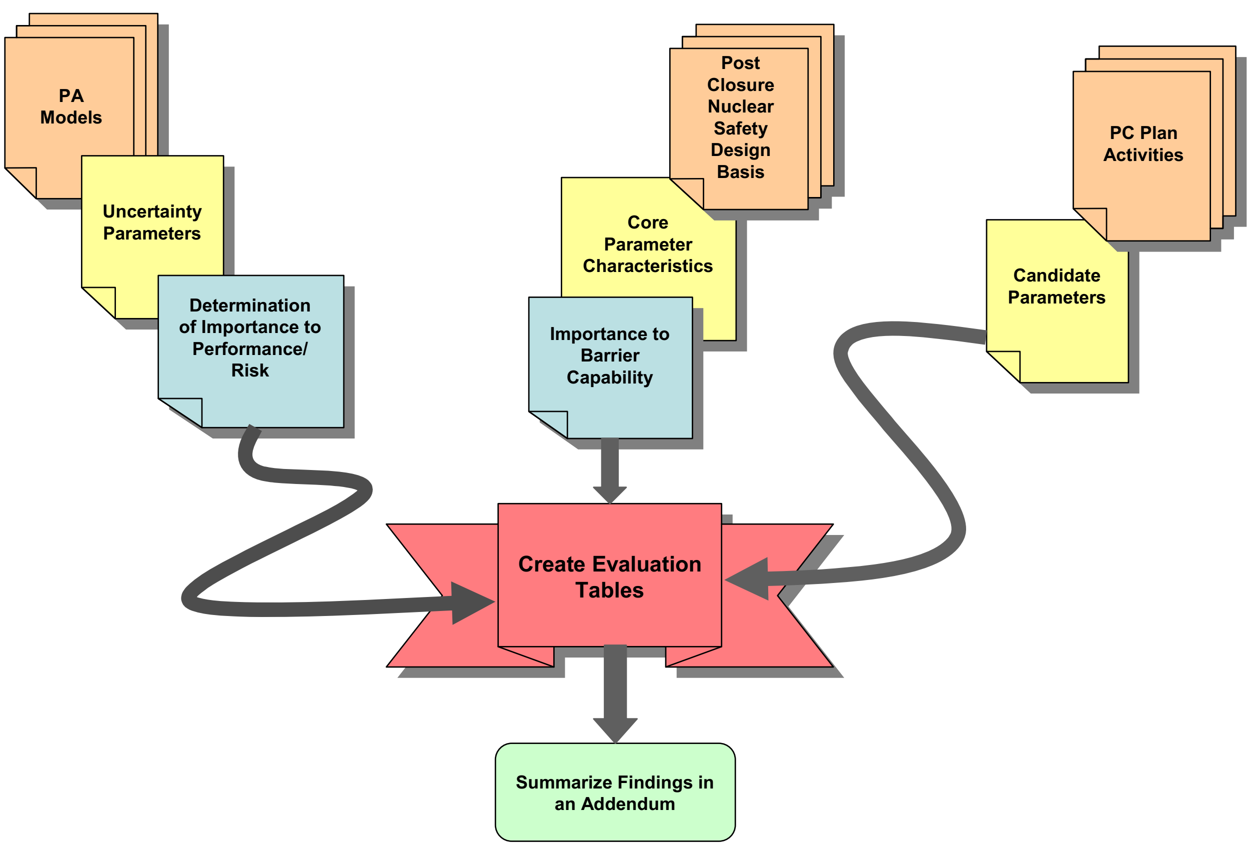


Figure A-1[a]. Performance Confirmation Evaluation for Completeness

A.4[a] DISCUSSION

The performance confirmation activities as documented in the PC Plan were developed using risk insights to focus attention on issues important to public health and safety. The approach was based on three criteria applied to a set of parameters identified by the subject matter experts: (1) how sensitive is barrier capability and system performance to the parameter, (2) what is the level of confidence in the current knowledge about the parameter, and (3) how accurately can information be obtained by a particular test activity. This process facilitated selection of activities that were designated risk-informed and performance-based. This selection process included knowledge of the TSPA used for site recommendation as well as the technical basis of ongoing science. The models used to develop the compliance analysis have been updated over the few years since the multi-attribute utility analysis was used to identify the performance confirmation activities. Hence, the primary purpose of this review is to ensure that the license application includes an appropriate performance-based, risk-informed confirmation program.

A.4.1[a] TSPA Models/Parameters Importance to Dose

The evaluation team applied their judgment to the entire list of models and parameters that support the postclosure technical baseline. For evaluation purposes, the team assigned ranking of High, Medium, or Low to each model and parameter. Although this part of the evaluation is subjective, the panel used the following guidelines to help assign rankings.

High. A rating of high is allocated to an uncertain parameter if a change in that parameter from the mean to the 95th percentile results in change of dose by a factor of 5. Similarly, the absence of a model process or feature, or absence of a parameter (e.g., by removing the model or assigning a null value to the controlling parameter in a TSPA sensitivity analysis), would generate a high rating if it changed the results by an equivalent amount.

Medium. A rating of medium is assigned to an uncertain parameter when a change from a mean value to the 95th percentile results in change of dose by a factor of 2. Similarly, the absence of a model process or feature, or absence of a parameter (e.g., by removing the model or assigning a null value to the controlling parameter in a TSPA sensitivity analysis), would generate a medium rating if it changed the results by an equivalent amount.

Low. A designation of low is given to any model or parameter that is deemed below medium.

It should be noted that values for standard rank regression coefficient (SRRC) were also used to guide the panel's qualitative evaluations. The SRRC values were available from Appendix K of the TSPA analysis model report (SNL 2008 [DIRS 183478]) and are described in Section A.4.2[a]. The evaluation and ranking of each TSPA model is summarized by model below.

<u>Models and Evaluation</u>

<u>Infiltration</u>. The importance of surface infiltration to total expected dose to the RMEI is evaluated as low for the first 10,000 years. No evaluation was performed for the post-10,000-year analyses, as percolation is prescribed by the proposed NRC rule at 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]). The effect of infiltration is quantified in the TSPA through unsaturated zone (UZ) flow and drift seepage. However, since drip shields are intact until about 200,000 years, no advection through waste packages is possible in the first 10,000 years except in the low-probability cases of early drip shield failure and igneous intrusion. Thus, this model is ranked as having low importance, since it will have limited influence on radionuclide releases from the waste package for the first 10,000 years (even though seepage rates determine how radionuclides are released from the invert into the UZ). Infiltration is more important after 400,000 years, when drip shields have failed, and general corrosion patches begin to appear in waste packages. At that point, advective flow of seepage water through the waste package is more likely, and solubility-limited radionuclides can be transported out of the waste package by advection. Under these conditions, infiltration plays a relatively important role. As noted above, deep percolation is prescribed by the proposed rule at 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

Performance confirmation activities related to the infiltration model include precipitation monitoring, subsurface mapping, UZ testing, seepage monitoring, and subsurface water and rock testing. Precipitation is among the most important factors for determining the net infiltration. The spatial distribution of net infiltration affects the patterns of percolation in the UZ and therefore of seepage. Seepage in turn is a driving force for release and transport of radionuclides from the EBS, and is important to the TSPA. This process is tested through planned seepage monitoring and subsurface water and rock testing activities in the confirmation program. Multiple locations are selected to facilitate spatial coverage for these activities.

UZ Flow. The importance of UZ flow to repository performance is evaluated as low for the 10,000-year period and medium for the post-10,000-year period. The UZ flow model predicts the flow of groundwater through the UZ, both above and below the repository, resulting from infiltration. The importance of this model is correlated with net infiltration and seepage, and impacts advective release and transport of solubility-limited radionuclides at later times, as discussed above. The NRC proposed percolation range for post-10,000 years is 13 to 64 mm/yr as prescribed by the proposed rule at 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]), and long-term dose is approximately proportional to the deep percolation rate; hence, there is medium importance for the post-10,000-year period (although infiltration was not evaluated for this period).

Performance confirmation activities pertaining to the UZ flow model include precipitation monitoring, subsurface water and rock testing, subsurface mapping, UZ testing, and seepage monitoring.

Engineered Barrier System (EBS) Thermal-Hydrologic (TH) Environment. The importance of the EBS TH environment to repository performance is evaluated as medium for the 10,000-year period and low for the post-10,000-year period. The TH environment model predicts the variation in temperature, humidity, and water saturation over time resulting from the heat output from waste packages and interactions with the surrounding host rock and percolating water. During the first 10,000 years, the TH environment is of medium importance to repository performance, because heat can drive away water from the emplacement drifts, precluding transport of radionuclides if any waste packages were to fail. In addition, heat can also strongly influence the chemical environment in the first few thousand years and weakly influence temperature-dependent waste package general corrosion. The TH environment is not important to repository performance in post-10,000-year analyses because temperatures will have returned nearly to ambient, and have little impact on repository conditions, even considering uncertainties associated with thermal processes that control the rate of cooldown.

Performance confirmation activities pertaining to the EBS TH repository performance include seismicity monitoring, subsurface mapping (e.g., for rock characteristics that control thermal properties), drift inspection, and monitoring associated with the thermally accelerated drift (in-drift environment monitoring and near-field monitoring).

Drift Seepage. The importance of drift seepage to repository performance is evaluated as low for the 10,000-year period and medium for the post-10,000-year period. Drift seepage is correlated with percolation flux (UZ flow) and similarly impacts advective release of solubility-limited radionuclides. Advective releases are not expected in the first 10,000 years, so this model is not given a high ranking. However, it is given a medium ranking because: (a) seepage results in advective transport through the invert, (b) seepage increases release rates from the EBS, and (c) seepage determines whether the releases enter the fractures of the UZ rather than the matrix. Releases to fractures decrease radionuclide travel time from the EBS to the saturated zone (SZ). Similar to the discussion for UZ flow, drift seepage is more important after 10,000 years, and particularly after 400,000 years when drip shields have failed and general corrosion patches appear in waste packages. At that point, advection through waste packages is more likely, and solubility-limited radionuclides can be transported by advection out of waste packages. Under these conditions, seepage plays a moderately important role.

Performance confirmation activities pertaining to the drift seepage model include seepage monitoring, subsurface mapping, unsaturated zone testing, and thermally accelerated drift in-drift environment monitoring.

Drift Wall Condensation. The importance of drift wall condensation to repository performance is evaluated as low for the 10,000-year period and low for the post-10,000-year period. This ranking is based on the fact that, although condensation in a drift can potentially result in a corrosive environment and advective releases even where seepage does not occur, or contribute to advection under seepage conditions, condensation dripping rates are small and conditions for occurrence are limited compared to seepage, so that drift wall condensation is predicted to be insignificant after 10,000 years.

Drift inspection and thermally accelerated drift in-drift environment monitoring are the performance confirmation activities that address drift wall condensation.

Drift Degradation. The importance of drift degradation to repository performance is evaluated as low for the 10,000-year period and medium for the post-10,000-year period. Importance to dose is low for 10,000 years because large magnitude events are rare during this period, so little degradation is expected. The relative importance increases to medium for the post-10,000-year period because rubble accumulates as the number of low-magnitude events grows, so that the likelihood of drip shield damage from successive events increases. In addition, the drip shields and waste packages thin due to general corrosion processes at later times, making them more susceptible to damage. Drift collapse and accumulated rubble on the drip shield and/or waste package can alter the TH conditions, increase seepage, and affect drip shield and waste package damage.

Performance confirmation pertaining to drift degradation is conducted under the seismicity monitoring, construction effects monitoring, and drift inspection activities.

EBS Chemical Environment: Near-Field Chemistry and Chemical Environment. The importance of near-field chemistry to repository performance is evaluated as high for the 10,000-year period and low for the post-10,000-year period. Note that the high rating for 10,000 years is based on conservative reasoning, which is conditioned on the drip shield failing to perform its diversion function. The near-field chemistry model determines the aqueous chemistry on drip shield and waste package surfaces and in the invert. Aqueous chemistry on the surface of the waste package can determine if localized corrosion will occur. Aqueous chemistry in the invert controls radionuclide solubilities and colloid stability. The near-field chemistry model is highly important to repository performance during the first 10,000 years, primarily for chemistry on the waste package surface and the determination that localized corrosion of the drip shield will not occur. This chemistry is a function of both the composition of the seepage entering the drift and the evolution of that seepage within the drift. The near-field chemistry is of low importance to repository performance in the post-10,000-year period because as ambient temperature conditions are approached, the near-field water chemistry on the drip shield and waste package surfaces and in the invert approaches ambient in situ chemical conditions, making the potential for initiation of localized corrosion insignificant.

The model for EBS environment, particularly the near-field chemistry and chemical environment, and interactions with introduced materials, are addressed by performance confirmation activities for waste package monitoring, waste form testing, corrosion testing, seepage monitoring, drift inspection, and aspects of the thermally accelerated drift in-drift environment monitoring and near-field monitoring.

Waste Package and Drip Shield Degradation: Drip Shield Degradation. The importance of drip shield degradation to repository performance is evaluated as high for the 10,000-year period and medium for the post-10,000-year period. Chemical degradation of the drip shield is evaluated as highly important to repository performance over the first 10,000 years, because the presence of an intact drip shield prevents waste package degradation. Tests and analyses indicate that localized corrosion of the drip shield would not initiate under the range of representative repository environments. Seepage-induced localized corrosion of the waste package will not occur during the first 10,000 years if deleterious seepage waters are diverted by the drip shield. Intact drip shields also prevent rockfall damage to waste packages and human intrusion into waste packages. When all drift seepage is diverted from the waste packages by intact drip shields, advective releases from waste packages cannot take place.

Drip shield degradation is less important over the post-10,000-year period, because drip shields begin to fail after about 200,000 years, based on current estimates of the general corrosion rate, and contribute little to repository performance thereafter. When waste packages begin to fail by general corrosion, after about 400,000 years, all drip shields will have failed, so degradation of the drip shield no longer has any impact. Longer-term corrosion tests of drip shield materials

(Titanium Grades 7 and 29) are planned as confirmatory tests to reduce uncertainty of estimates for drip shield corrosion failure.

Several performance confirmation activities address drip shield degradation, including corrosion testing activities, corrosion testing of thermally accelerated drift samples, thermally accelerated drift in-drift environment monitoring, dust buildup monitoring, and drift inspection.

Waste Package and Drip Shield Degradation: Waste Package Degradation. Degradation of the waste package is highly important to repository performance for both the 10,000-year period and the post-10,000-year period. The nominal performance of codisposal (CDSP) and commercial spent nuclear fuel (CSNF) waste packages is similar, with high resistance to localized corrosion and very low rates of general corrosion during the first 10,000 years. CDSP waste packages are more susceptible to stress corrosion cracking resulting from seismic motion than CSNF waste packages, because the transportation, aging, and disposal (TAD) canister in CSNF waste packages provides additional structural resilience and protection from seismic damage. Seismic-induced stress corrosion cracking is the dominant waste package breach mode for several hundred thousand years; on average, general corrosion failures begin after about 400,000 years.

Waste package degradation is addressed by performance confirmation corrosion testing activities and corrosion testing of thermally accelerated drift samples.

EBS Flow. EBS flow is of low importance to repository performance for the 10,000-year period and of medium importance for the post-10,000-year period. The EBS flow model partitions seepage flux into the drift, diverting all or a portion of the flux around the drip shield and waste package into the invert, depending on whether the drip shield and waste package have failed. Flow through the EBS plays a relatively minor role, because drip shields and waste packages remain intact and prevent advective flows for several hundred thousand years. After about 400,000 years, all drip shields will have failed, and general corrosion patches will have begun to appear in waste packages, allowing potentially significant advective flows through the waste packages in dripping environments. Flow through the invert in dripping environments causes releases to enter the fractures of the UZ.

The performance confirmation activity that addresses the EBS flow model is thermally accelerated drift in-drift environment monitoring.

Radionuclide Inventory. The radionuclide inventory of a waste package is of low importance in both 10,000-year and post-10,000-year periods. The inventory provides a source term for TSPA and input to the multiscale thermohydrologic model; it includes the waste stream, burn-up credit, the number and types of waste packages, waste package lengths, initial radionuclide masses, radionuclide half-lives, the composition of the representative unit cell of waste packages, and thermal decay curves for the unit cell and for each of its waste packages.

There is no performance confirmation activity concerned with radionuclide inventory. The inventory characteristics indicated above are fixed in the TSPA basis. Thermal and waste inventory are analyzed by implementing administrative controls.

<u>In-Package Chemistry</u>. The in-package chemistry model is of low importance in 10,000-year analyses and of medium importance in post-10,000-year analyses. The in-package chemistry model provides the chemical conditions within the breached waste package and in the invert for locations where there is advective transport from the waste package. These chemical conditions influence waste form degradation, radionuclide solubility, and colloid stability. During the 10,000-year period, mobile ^{99}Tc and ^{129}I will be important dose contributors; however, these radionuclides are not solubility limited under repository conditions and are therefore less affected by in-package chemical conditions. It should be noted that the degradation rate of high-level waste glass (HLWG) is controlled by in-package chemistry, and this rate influences the rate at which ^{99}Tc is made available for transport.

During the post-10,000-year period, in-package chemistry has a significant influence on the release of important late-time radionuclides, such as ^{226}Ra, ^{237}Np, ^{239}Pu, and ^{242}Pu, because these radionuclides are solubility limited, and in-package chemistry controls the solubilities.

Performance confirmation activities that examine in-package chemistry are included in waste form testing.

<u>Cladding Degradation</u>. The importance of cladding degradation to repository performance was not evaluated because credit is taken only for naval spent nuclear fuel (SNF) cladding; by assumption, no credit is taken for CSNF cladding.

No PC activity is needed. Although this has been identified as ITBC, the FEP is dealt with in a conservative manner in performance assessment and the barrier capability is not realized.

<u>Waste Form Degradation: CSNF, DSNF, HLWG</u>. The commercial spent nuclear fuel (CSNF) and defense spent nuclear fuel (DSNF) waste form degradation models are of low importance in both the 10,000-year period and post-10,000-year periods. The HLWG waste form degradation models are of high importance in the 10,000-year period and low importance in the post-10,000-year period. The degradation rates of the CSNF and DSNF waste forms are relatively rapid. Important releases early on from CDSP waste packages, i.e., mobile ^{99}Tc, are not solubility limited. Since the majority of the inventory of ^{99}Tc is in HLWG, degradation rates for HLWG are of high importance in the 10,000-year period.

Performance confirmation activities that concentrate on waste form degradation are included in waste form testing and elements of corrosion testing.

<u>Dissolved Concentrations</u>. The dissolved concentrations model is of low importance in the 10,000-year period and medium importance in the post-10,000-year period. This model is potentially important for solubility-limited radionuclides, such as ^{226}Ra, ^{239}Pu, ^{242}Pu, and ^{237}Np, particularly at later times during the post-10,000-year period, when advective releases from the EBS become important.

Performance confirmation testing for dissolved concentrations include seepage monitoring and waste form testing.

EBS Colloids. The colloid concentrations and stability model is of low importance in both the 10,000-year period and post-10,000-year period. Plutonium colloids contribute to dose, but their contribution is not significant.

Performance confirmation waste form testing activities account for EBS colloid concentrations and stability.

EBS Transport. The EBS Transport model is of high importance in the 10,000-year period and of medium importance in the post-10,000-year period. The EBS transport model estimates the releases of radionuclides from failed waste packages by means of diffusion and/or advection from degraded waste forms through the interior of the waste package, through the breached waste package wall, and through the invert to the UZ. Colloid-facilitated transport and sorption of radionuclides on corrosion products inside the waste package are accounted for. Transport in the EBS is highly important for the first 10,000 years because releases from the EBS are dominated by diffusion from waste packages that are breached by seismic-induced damage. Prior to waste package general corrosion failures beginning at about 400,000 years, the importance of EBS transport is similar to its importance during the first 10,000 years because stress corrosion cracking is still the dominant failure mechanism. Subsequently, when large general corrosion patches appear, unconstrained mass transfer of water vapor and oxygen into breached waste packages is a reasonable approximation, so the conservative treatment in the EBS transport model has a less significant impact on dose estimates.

Performance confirmation activities that address EBS transport include: waste form testing, corrosion testing, thermally accelerated drift near-field and in-drift environment monitoring, and corrosion testing of the thermally accelerated drift samples.

UZ Transport. The UZ transport model is of low importance in the 10,000-year period and of low importance in the post-10,000-year period. The UZ transport model calculates the movement of radionuclides released from the EBS through the UZ beneath the repository and into the SZ. UZ transport is of low importance to dose for both 10,000-year and post-10,000-year analyses, because radionuclide travel times from the EBS to the SZ through the UZ are minimal due to the relatively short pathway and relatively rapid flow and transport.

Performance confirmation activities that address UZ transport include: subsurface water and rock sampling, UZ testing, and subsurface mapping.

SZ Flow and Transport. The importance of SZ flow and transport to repository performance for both the 10,000-year period and the post-10,000-year period is medium. The SZ flow and transport model simulates groundwater flow in the vicinity of the repository and calculates the mass of radionuclides carried from the saturated zone beneath the repository to the accessible environment. This model has a relatively important influence on dose, primarily because of the long travel times, matrix diffusion in the volcanic units, and sorption in the alluvium.

Performance confirmation activities that address SZ flow and transport include: SZ fault hydrology testing, SZ monitoring, and SZ alluvium testing.

Mechanical Damage due to Seismic Ground Motion. The mechanical damage caused by seismic ground motion is highly important to repository performance for both the 10,000-year period and the post-10,000-year period. Results from the 10,000-year analyses show that mechanical damage is the major cause of degradation of the CDSP waste package by the process of stress corrosion cracking. Mechanical damage is an important determinant for CSNF waste package degradation by stress corrosion cracking for an analysis period as long as 400,000 years. At longer analysis times (beyond 600,000 years), waste package failures resulting from nominal processes (mainly weld flaws exposed by general corrosion) become so extensive that additional damage from seismic ground motion is indistinguishable from the nominal processes, so the dose due to nominal processes is equivalent to the dose estimated by the mechanical damage models.

Performance confirmation activities that address mechanical damage due to seismic ground motion include: seismicity monitoring, drift inspection, construction effects monitoring, and corrosion testing.

The model-by-model summary above identifies the performance confirmation activity or activities that apply to each of the TSPA models. Two TSPA models do not have an associated confirmation activity. There is no performance confirmation activity required for the radionuclide inventory because the responsibility for thermal and waste inventory are administrative. Cladding degradation is implemented conservatively in performance assessment, the barrier capability is not realized, and therefore no confirmation activity is required. All the pertinent TSPA models have associated performance confirmation activities.

A.4.2[a] TSPA Models/Parameters Significance to Uncertainty

The second step in this completeness review examines parameters associated with the models discussed in Section A.4.1[a]. The evaluation of parameters is a level of detail below the assessment of the models. Insight regarding the most significant parameters is provided in this section and this information is consistent with the material used for the license application safety case.

In Appendix K of the TSPA analysis/model report (SNL 2008 [DIRS 183478]), stepwise rank regression is used to identify those parameters that make the largest contribution to the uncertainty in dose to the RMEI. In a stepwise rank regression, the single independent variable that makes the largest contribution to the uncertainty in the dependent variable is selected in the first step. Then, at the second step, the single independent variable that, in conjunction with the first variable, makes the largest contribution to the uncertainty in the dependent variable is selected. This process then continues until no additional variables are found that make identifiable (i.e., significant) contributions to the uncertainty in the dependent variable; at this point, the stepwise selection process terminates.

In the context of stepwise regression analysis, variable importance is indicated by the sign and size of the standardized rank regression coefficients (SRRCs). SRRCs provide an estimate of the monotonic relationship between input variables and the output variable under consideration. Further, a positive SRRC indicates that the independent variable and dependent variable (in this case, total expected dose to the RMEI (*EXPDOSE*)) tend to increase and decrease together, whereas a negative SRRC indicates that the independent and dependent variable tend to move in opposite directions. Low, medium, and high rankings are based on the following values of SRRCs:

High:	SRRC > |0.3|
Medium:	|0.1| < SRRC ≤ |0.3|
Low:	SRRC ≤ |0.1|

Values of SRRC as bracketed above were compared to the sensitivity analysis results in Figures K.8.1-2 and K.8.2-2 of the TSPA analysis/model report (SNL 2008 [DIRS 183478], Appendix K). Those parameters meeting the medium and high thresholds are summarized in Table A-1[a].

Table A-1[a]. Summary of Input Parameters Important to Uncertainty for the 10,000-Year and Post-10,000-Year Periods

	10,000-Year Period [a]		Post-10,000-Year Period [b]	
	Medium Importance	**High Importance**	**Medium Importance**	**High Importance**
1	IGRATE	SCCTHRP	EP1LOWPU	IGRATE
2	SZGWSPDM		EP1LOWNU	WDGCA22
3	MICTC99		SCCTHRP [c]	SZGWSPDM
4	INFIL		INFIL	SCCTHRP [c]
5	SZFISPVO		SZFISPVO	
6	MICC14		EP1NPO2	
7	DSNFMASS		MICNP237	
8			SZCONCOL	
9			MICTC99	
10			GOESITED	
11			PHCSS	

[a] Determined from the Boolean union of data from SNL 2008 [DIRS 183478], Figure K.8.1-2(a)[a], using classification rules from text.

[b] Determined from the Boolean union of data from SNL 2008 [DIRS 183478], Figure K.8.2-2(a)[a], using classification rules from text.

[c] Included in both Medium and High categories to show that the importance of stress corrosion cracking (SCC) decreases in the assessments at approximately 200,000 years and beyond, when general corrosion gradually dominates the modes of waste package damage.

The significance to uncertainty of models is based on the uncertainty of parameters used in those models, as described in this section. Further, additional insights for parameters of importance can be developed based on identifying those radionuclides that are key contributors to expected dose. For the first 10,000-year period, the primary contributors to dose are ^{99}Tc and ^{239}Pu. For the post-10,000-year period, the primary contributors are ^{129}I, ^{242}Pu, ^{239}Pu, ^{226}Ra, and ^{237}Np (SNL 2008 [DIRS 183478]). Parameters that control transport of these radionuclides to the accessible environment are identified as important parameters; these parameters include solubilities and sorption coefficients, both in the EBS and natural system. In turn, these parameters are strong functions of the thermal-hydrologic environment in the emplacement drifts and the chemical environment within the waste package and invert.

A key parameter in the seismic scenario class ground motion modeling case is the stress threshold for stress corrosion cracking initiation, used to estimate when waste packages will begin to fail due to stress corrosion cracking. Testing will confirm the appropriateness of the parameters used or determine the degree of conservatism. Long-term corrosion tests of waste package materials (Alloy 22 and Stainless Steel Type 316L) will confirm the appropriateness of parameters used to estimate when waste packages will begin to fail due to general corrosion. Localized corrosion tests will reduce the uncertainty associated with whether localized corrosion can initiate under the range of representative repository environments.

Several parameters are included in the analysis of net infiltration. A sensitivity analysis was conducted using the infiltration model to determine which parameters contributed most to uncertainty in predictions of net infiltration. When aleatory uncertainty is fixed, the sensitivity analyses are consistent for the three climates and indicate that the most important physical parameters are Soil Depth Class 4 (for shallow depth soils) and HC_579 (water holding capacity for soil group 5/7/9) (SNL 2008 [DIRS 182145], Section H.4). The most common soil grouping within the YMP site is soil group 5/7/9. The only uncertain input parameter to the UZ flow model is INFIL, which is discussed along with other parameters important to uncertainty in the following text. The ranges of uncertainty for key parameters such as Soil Depth Class 4 are sampled in developing the range of data represented by parameter INFIL for TSPA. Confirmatory activities could inform the distributions for parameters such as Soil Depth Class 4, better defining the aleatory uncertainties, but are considered to be unlikely to significantly change the epistemic uncertainty ranges for individual contributing parameters. Hence, the performance confirmation activities planned to address infiltration focus on integrated measures of infiltration impact on the site hydrology, as discussed in Section A.4.1[a].

The biosphere model has some uncertain parameters defined at the level of maximum detail in the model; these substituent parameters are identified and quantified in the model report (SNL 2007 [DIRS 177399], Section 6.6.3). Substituent parameter values are constrained by observations from present-day Amargosa Valley, by analogue sites, and from parameter information published in the technical literature. The biosphere model also contains features and parameters that are controlled by regulation (e.g., 10 CFR 63.305 [DIRS 180319]), and by international radiation protection protocols (e.g., ICRP 1991 [DIRS 101836]). The sensitivity of TSPA results to certain biosphere dose conversion factor (BDCF) uncertainties (i.e., MICC14, MICNP237, and MICTC99 in Table A-1) can therefore be traced to a few substituent parameters identified in the biosphere model report (SNL 2007 [DIRS 177399], Section 6.13). Whereas the performance confirmation program is designed to provide data that address the operation of designated barriers after permanent closure (consistent with 10 CFR 63.131(a)(2) [DIRS 180319]), the biosphere is not identified as such a barrier for the postclosure performance assessment (SNL 2008 [DIRS 177464]). This is appropriate because many aspects of the biosphere model and its risk sensitivity are controlled by factors not subject to confirmation, including regulatory input and international protocols.

Input Parameters Important to Uncertainty

The input parameters presented in Table A-1[a] are defined below and listed in alphabetical order (SNL 2008 [DIRS 183478], Tables K3-1 Table K3-3). These parameters are related to model inputs and outputs. The review panel considered the importance of the models to dose, as described above. Next, the significance to uncertainty is ranked, based qualitatively on the correlation coefficients. A discussion of each parameter in alphabetical order is presented below. Each parameter is related to a performance confirmation activity, if applicable.

DSNFMASS – Scale factor used to characterize uncertainty in radionuclide content of DSNF (dimensionless). The sampled multiplier is applied to the nominal DSNF values for all radionuclides except ^{238}U. A radionuclide mass uncertainty multiplier is selected at the beginning of each realization and applied to each waste package that is assumed breached. The selected uncertainty multiplier is held constant during each realization run. The uncertainty for this parameter was developed based on the initial radionuclide inventory of the repository. The radionuclide inventory is monitored by repository operations, so this is not considered for incorporation in a performance confirmation activity.

EP1NPO2 – Logarithm of the scale factor used to characterize uncertainty in NpO_2 solubility at an ionic strength below 1 molal (dimensionless). This parameter, ε_1, is used to account for uncertainties in the input thermodynamic property data used to calculate the solubility lookup tables for Np in the dissolved concentrations model. NpO_2 solubility is included in performance confirmation waste form testing.

EP1LOWNU – Logarithm of the scale factor used to characterize uncertainty in uranium solubility under nominal or seismic conditions at an ionic strength below 1 molal (dimensionless). This parameter, ε_1, is used to account for uncertainties in the input thermodynamic property data used to calculate the solubility lookup tables for U in the dissolved concentrations model. U solubility is included in performance confirmation waste form testing.

EP1LOWPU – Logarithm of the scale factor used to characterize uncertainty in plutonium solubility at an ionic strength below 1 molal (dimensionless). This parameter, ε_1, is used to account for uncertainties in the input thermodynamic property data used to calculate the solubility lookup tables for Pu in the dissolved concentrations model. Pu solubility is included in performance confirmation waste form testing.

GOESITED – Density of sorption sites on goethite (nm^{-2}), representing the availability of sorption sites on corrosion products, mainly from steel or stainless steel, inside the waste package. Such sites sorb certain radionuclides and contribute to attenuation of dissolved radionuclide concentrations.

IGRATE – Annual frequency of intersection of the repository footprint by an igneous event (yr^{-1}). An igneous event includes an intrusion by magma and may also include eruptive conduits intersecting the repository. IGRATE is treated as an epistemic uncertainty and is sampled from the distribution for each TSPA model realization. Implementation of this parameter captures the bounding case, and therefore no performance confirmation activity is planned for this specific parameter.

INFIL – Pointer variable for determining infiltration conditions: nominal 10th, 30th, 50th, or 90th percentile infiltration cases (dimensionless). This parameter provides the weighting factors for these four cases, for the three climates used in TSPA for the first 10,000 years. The parameters contained within the TSPA parameter INFIL correspond to infiltration uncertainty cases 1 through 4, proceeding from the lowest nominal percentile to the highest. The use of all these percentiles is intended to cover the uncertainties associated with the infiltration for each climate. The two future climates—the monsoon and glacial-transition—account for possible climate-induced changes in precipitation and net infiltration. Activities to evaluate this parameter include precipitation monitoring, subsurface mapping, UZ testing, seepage monitoring, and subsurface water and rock testing.

MICC14 – Groundwater BDCF for ^{14}C in modern interglacial climate ((Sv/yr)/(Bq/m^3)). The groundwater BDCFs predict, in a stochastic manner to allow for parametric uncertainty, the annual dose (Sv/yr) to the RMEI for a unit activity concentration (1 Bq/m^3) in the groundwater for each radionuclide considered by TSPA. This factor is developed from an extensive number of input parameters from multiple external sources detailed in the biosphere model, so a performance confirmation activity is not planned.

MICNP237 – Groundwater BDCF for ^{237}Np in modern interglacial climate ((Sv/yr)/(Bq/m^3)). This factor is developed from an extensive number of input parameters from multiple external sources detailed in the biosphere model, so a performance confirmation activity is not planned.

MICTC99 – Groundwater BDCF for ^{99}Tc in modern interglacial climate ((Sv/yr)/(Bq/m^3)). This factor is developed from an extensive number of input parameters from multiple external sources detailed in the biosphere model, so a performance confirmation activity is not planned.

PHCSS – Pointer variable used to determine pH in CSNF Cell #1 (waste form domain) under liquid influx conditions (dimensionless). Controls solubilities for certain radionuclides, particularly actinides, which may be solubilized by high or low pH conditions.

SCCTHRP – Residual stress threshold for SCC nucleation of Alloy 22 (as a fraction of yield strength in MPa). The threshold stress is taken to be 90% to 105% of the input value for yield strength. The abstraction in the TSPA of SCC initiation and growth, due to both incipient cracks and weld flaws, uses the slip dissolution-film rupture mechanism. Inputs to this slip dissolution mechanism include the residual stress threshold along with input data for the threshold stress intensity factor, an incipient crack size, and crack growth-rate parameters. The uncertainty in residual stress threshold is based in part on stress distributions obtained in finite element modeling of waste package lid welds. The time required for cracks to penetrate the waste package wall and thereby allow releases to occur depends partly on the general corrosion rate of Alloy 22 and the thickness of the outer corrosion barrier (OCB). Activities to evaluate this parameter are included in performance confirmation corrosion testing.

SZCONCOL – Ambient concentration of colloids in groundwater (g/mL). This parameter is used to calculate the retardation of radionuclides in colloidal transport. This parameter depends on the groundwater chemistry, specifically, the ionic strength and pH, which determines whether colloids are stable under ambient conditions. These measurements are included in SZ hydrology testing and monitoring performance confirmation activities.

SZFISPVO – Flowing interval spacing in fractured volcanic units (m). The flowing interval spacing and flowing interval porosity are used to define the effective area to flow in the fractured volcanic units. A flowing interval is defined as a fractured zone that transmits fluid in the SZ, as identified through borehole flow meter survey data. The flowing interval spacing is the distance between the midpoints of each flowing interval. The flowing interval approach and the resulting uncertainty distribution implicitly accounts for the potential existence of undetected features, such as fracture zones through which groundwater flow is channeled, in the fractured volcanic units of the SZ. Activities to evaluate these parameters are included in performance confirmation SZ testing.

SZGWSPDM – Logarithm of the scale factor used to characterize uncertainty in groundwater specific discharge (dimensionless). Uncertainty exists in the groundwater scaling factors for climate change in the SZ. The uncertainty is captured by the stochastic parameter groundwater specific discharge multiplier and is based on single- and multi-well hydraulic testing of wells in the fractured volcanic units near Yucca Mountain. The uncertainty in SZGWSPDM is applied to all of the climate states. Activities to evaluate this parameter are included in performance confirmation SZ testing.

WDGCA22 – Temperature-dependent slope term of Alloy 22 general corrosion rate (K). The temperature-dependence term represents the effect of temperature on corrosion rates of Alloy 22 based on polarization resistance measurements using a wide variety of specimen configurations, metallurgical conditions, and exposure environments (i.e., water chemistries). The higher the value of the temperature-dependence term, the greater the dependence of general corrosion rate on temperature. Activities to evaluate these parameters are included in performance confirmation corrosion testing.

As can be appreciated, not all parameters of medium or high importance to uncertainty can be measured, monitored, or tested (biosphere dose conversion factor, for example). However, many of the parameters contributing most significantly to uncertainty are related to specific performance confirmation activities. These parameters and their relationship to the safety case are included in the detail of the PC test plans.

Thus far, this assessment has examined the TSPA models and parameters significant to uncertainty. An additional cross-check between the licensing bases can be made to the performance confirmation activities. This is accomplished by using the PoNSDB and the assessment in that document of the core parameter characteristics. The PoNSDB tables include a summary of the effect of a particular FEP on barriers. The PoNSDB also identifies the core parameter characteristics associated with the determination of ITBC. A comparison is then possible between the ITBC core parameter characteristics and performance confirmation activities, as discussed in the following section.

A.4.3[a] PoNSDB Evaluation

The PoNSDB has identified features/components of barriers that are important to waste isolation (ITWI) as well as features/components and parameter characteristics that are ITBC. Capability has been defined as the ability or potential of a feature/component to contribute to the function of the barrier, which may or may not be realized in the TSPA. The parameter characteristics important to barrier capability were considered aspects of the barrier's feature/component that contribute to the feature/component's capability and support the technical basis of the TSPA. In the PoNSDB, these parameter characteristics were categorized as either "core parameter characteristics," which are not controlled and manipulated, or "control parameter characteristics" that can be controlled and manipulated by design, construction, or operations. Further, these core and control parameter characteristics were categorized as ITBC if they are the attribute(s) of the feature that enable it to prevent or substantially reduce the rate of movement of water or radionuclides from the repository to the environment, or prevent the release or substantially reduce the release rate of radionuclides from the waste.

The methodology for the identification of ITBC core and control parameter characteristics is described in the PoNSDB. The process starts with an examination of FEPs and their screening justifications. The parameter characteristics associated with each FEP were identified, and the screening justification is further constrained the categorization of ITBC relevant to each barrier feature/component. Lastly, if the feature/component is associated with at least one ITBC parameter characteristic <u>and</u> contributes significantly to the barrier capability relative to the other features/components of the barrier, then that feature/component is also classified as ITWI.

The tables in the PoNSDB appendices are organized by barrier, feature, the applicable FEP, and whether it is included or excluded from the performance assessment models. For this comparison to the confirmation activities, the organization of the PoNSDB tables is replicated and assembled at the end of this appendix. Table A-2[a] contains a column which discusses the effect of the FEP on barrier capability. The effect of the feature on the barrier in the context of the FEP leads to the determination of whether the combination is ITBC. The PoNSDB also ascribes core parameter characteristics to the combinations of feature/FEP/effect on barriers/ITBC. The core parameter characteristics that are determined to be ITBC are compared and evaluated against the performance confirmation activities. Table A-2[a] embodies the comprehensive results of the comparison between the PoNSDB core parameter characteristics and the associated performance confirmation activities.

The analysis and understanding of the barrier capability are consistent with the technical bases of the performance assessment used to demonstrate compliance with 10 CFR 63.113(b) and (c), [DIRS 180319] as they are based on results from the FEP screening analyses. In some cases, FEPs that are important to barrier capability may be excluded from the TSPA, for example if that would produce inappropriately conservative estimates of dose.

In some cases, the feature/FEP circumstances lead to a determination of ITBC, but there may not be a need for a performance confirmation activity. For example, if the FEP is dealt with in a conservative manner in performance assessment, the capability may not be realized. If the barrier capability is not realized and the treatment is conservative in performance assessment, there is no requirement for a confirmation activity.

Table A-2[a] contains both included and excluded FEPs, because the performance confirmation program both confirms and challenges the bases of the license application. The performance confirmation activities that account for ITBC core parameter characteristic are noted in Table A-2[a]. In some cases, there is a cause-and-effect relationship, where a process such as corrosion must proceed before the feature such as the waste package would be susceptible to a

FEP such as advection of liquids. These types of relationships are required to be documented in the details of the PC test plans.

A.5[a] CONCLUSIONS

The evaluation affirms that the PC Plan activities support the technical basis for postclosure performance assessment of the natural and engineered barriers. It is the considered judgment of the evaluation panel that the PC Plan activities provide adequate coverage to confirm the license application basis. Though no new performance confirmation activities have been identified based on this analysis, considerable insight was gained on the scope of planned performance confirmation activities.

Extensive comparisons were made between the models and parameters used for the TSPA and the performance confirmation activities. The models implemented in TSPA capture the applicable FEPs. Each model was evaluated for importance to dose (i.e., performance) and significance to uncertainty. In certain cases, higher priority based on significance to dose or uncertainty can be inferred and will be considered as performance confirmation activities are described in test plans.

This evaluation went beyond TSPA models and parameters to assess the completeness of the PC Plan. The PoNSDB was used to correlate barrier features to FEPs and to establish the effect on barrier capability. The PoNSDB thereby provided a determination of ITBC and the associated core parameter characteristics. Core parameter characteristics represent a quantity or variable that contributes to barrier capability to prevent or reduce the flow of water or release and transport of radionuclides. Core parameter characteristics that are categorized as ITBC were correlated to performance confirmation activities. Candidate performance confirmation parameters would comprise a subset of the core parameter characteristics that are amenable to measurement and/or evaluation via testing or monitoring activities.

In Section A.4.1[a], the importance of models and parameters used in the TSPA was evaluated. This evaluation was based on both the professional judgment of analysts who are intimately familiar with the models and on a comparison to TSPA results. Parameters were identified whose uncertainties have significant effect on dose to the RMEI in the first 10,000-year period and in the post-10,000-year period, as determined in the TSPA. The parameters in TSPA models that are most significant to uncertainty were identified for comparison to planned performance confirmation activities. On the basis of this assessment, some indications of the most influential and significant TSPA parameters are evident.

This assessment also includes a review of performance confirmation activities and barrier characteristics. The PoNSDB was examined to determine core parameter characteristics that are ITBC. These characteristics derive from FEPs and therefore are consistent with the performance assessment models. Features and components determined to be ITBC in the PoNSDB would also be candidates for confirmation testing and monitoring. Note that planning for the seals testing activity (Section 3.3.3.1 of the parent report) is modified in Section 3.5.5[a] of this addendum.

This exercise was initiated to ensure that an adequate confirmation plan has been implemented and remains relevant to the license application bases, including the TSPA and PoNSDB. It was not the intent to prioritize or perhaps eliminate proposed activities at this time. The testing and monitoring details, including justification, parameter ranges, and condition limits, will be required in the individual PC test plans. Based on the evaluations herein, it is concluded that the planned activities are consistent with the license application basis.

A-6[a]. FEPS, BARRIER CAPABILITY, AND PC ACTIVITY

Table A-2[a] lists all of the included and excluded FEPs that have been identified as ITBC and thus have core parameter characteristics. Core parameter characteristics were obtained from Tables A-1, A-2, and A-3 of the PoNSDB (SNL 2008 [DIRS 177464]). Using the PC activity descriptions from the parent report as a guideline, the activities were associated with ITBC core parameter characteristics. Table A-2[a] provides the list of FEPs generally arranged from the surface and upper natural barrier, downward to the repository and the engineered barrier, then to the lower natural barrier. A description of the FEP is used as additional guidance for evaluating pertinent PC program activities.

Table A-2[a]. FEPs, Barrier Capability, and PC Activity

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Topography and Surficial Soils	1.2.02.01.0A Fractures **Included**	The hydrologic characteristics of fractured bedrock below the surficial soils are significant in affecting the amount of net infiltration into the repository, as the fractures and fracture properties affect the rate of water movement below the soil–bedrock contact, especially in areas of thin soils. Uncertainty in the fracture hydrologic characteristics, in particular fracture permeability and fracture filling, has been incorporated into the net infiltration model.	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	None. The conservative model treatment of infiltration does not take credit for significant retention in near-surface fractures, i.e., the capability of this feature is not realized in TSPA.
UNB	Topography and Surficial Soils	1.3.01.00.0A Climate Change **Included**	Climate change affects the amount and distribution of water that infiltrates into the surficial soils and underlying bedrock. Future climate analyses indicate that the climate at Yucca Mountain will evolve to a warmer and wetter monsoon climate followed by a cooler, wetter glacial-transition climate within the first 10,000 years after disposal and then by an even wetter full glacial climate within the period of geologic stability. The effects of climate change on groundwater flow in the unsaturated zone above the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the site-scale UZ flow model for the first 10,000 years and for the post-10,000-year period, using a distribution for the deep percolation rate that implements requirements of the proposed rule. The climate change effects the amount of water available for infiltration into the UZ.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	Precipitation monitoring Seepage monitoring Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Topography and Surficial Soils	1.4.01.01.0A Climate Modification Increases Recharge **Included**	Future climate change significantly affects the amount and timing of precipitation and temperature, which in turn affects net infiltration into surficial soils. The net effect of climate change after repository closure is to increase the amount of water that precipitates and can infiltrate through the surficial soils, eventually percolating through the unsaturated zone as recharge to the water table. The climate effect on net infiltration has been directly included in the assessment of performance and barrier capability by developing infiltration scenarios for each of three climates for the first 10,000 years after closure: present-day, monsoon, and glacial-transition. After that and through the period of geological stability (as proposed by 40 CFR 197 [DIRS 184076]), the climate modification on percolation and recharge is incorporated into the performance assessment using a distribution for the deep percolation rate that implements requirements of the proposed rule.	**ITBC:** Infiltration and Seepage **Non-ITBC:** Surface Soil Properties (including vegetation)	Precipitation monitoring Seepage monitoring Subsurface water and rock testing
UNB	Topography and Surficial Soils	2.2.03.02.0A Rock Properties of Host Rock and other Units **Included**	The hydrologic characteristics (e.g., permeability, porosity, capillarity, storage capacity) of the surficial soils and shallow bedrock above the repository are significant in affecting the amount of net infiltration following a precipitation event. The characteristics of the surficial soils also affect the soil retention and the time infiltrating water takes to pass below the root zone to become net infiltration (i.e., where it is not subject to further evapotranspiration processes). The hydrologic characteristics of the surface soils and shallow bedrock at Yucca Mountain, including associated uncertainty, most notably the permeability, are included in the assessment of the net infiltration and determined to be ITBC.	**ITBC:** Infiltration and Seepage Surface Soil Properties (including vegetation)	Seepage monitoring Subsurface water and rock testing
UNB	Topography and Surficial Soils	2.2.07.08.0A Fracture Flow in the UZ **Included**	The hydrologic characteristics of the surficial soils above the repository are significant in affecting the amount of net infiltration following a precipitation event. Fracture flow in the bedrock beneath the surficial soils affects the rate of water movement below the soil and bedrock contact, especially in areas of thin soils.	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	Seepage monitoring Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Topography and Surficial Soils	2.3.01.00.0A Topography and Morphology **Included**	Surficial topography significantly affects the amount of runoff of precipitation events. The topography and morphology of the ground surface above the repository are such that a portion of the precipitation that falls at Yucca Mountain is unavailable for infiltration due to surface runoff. Generally, the steeper slopes have more runoff and less infiltration than the more gentle slopes. Variability in slope angles and orientation and permeability of surficial rock and soil has been included in the infiltration model.	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	Seepage monitoring Subsurface water and rock testing
UNB	Topography and Surficial Soils	2.3.11.01.0A Precipitation **Included**	Precipitation is important in the evaluation of the net infiltration into the bedrock below the surficial soils. The temporal and spatial distribution of precipitation affects the amount of water available to potentially run off, evaporate, transpire, or infiltrate. Given the semi-arid climate at Yucca Mountain, there are long periods of net evapotranspiration from surficial soils, interrupted by short-duration precipitation events that can result in infiltration. Generally, greater net infiltration results from precipitation in cooler months when there is less potential for evapotranspiration. Net infiltration under present-day and future climates during the first 10,000 years after repository closure is calculated in the infiltration model. Historical precipitation cycles were used in the development of the future climate states. For the proposed post-10,000-year period of geologic stability, the precipitation effect is implicitly included by using a distribution for the deep percolation rate that implements requirements of the proposed rule.	**ITBC:** Infiltration and Seepage **Non-ITBC:** Surface Soil Properties (including vegetation)	Precipitation Seepage monitoring Subsurface water and rock testing
UNB	Topography and Surficial Soils	2.3.11.02.0A Surface Runoff and Evapotranspiration **Included**	Surface runoff may redistribute precipitation to areas away from the repository footprint where it may infiltrate. Surface water runoff and evapotranspiration are components in the water balance together with precipitation, infiltration, and change in storage. Surface runoff may produce erosion and could result in increased recharge through the washes and impoundments in low-lying areas. Both of these processes are included in the infiltration model for the first 10,000 years following repository closure. For the post-10,000-year period up to geologic stability, their effects are implicitly incorporated into the performance assessment by using the distribution of deep percolation rate as specified in the proposed rule.	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	Seepage monitoring Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Topography and Surficial Soils	2.3.11.03.0A Infiltration and Recharge **Included**	Infiltration is the net result of all surficial processes related to the availability of water. These processes include the effects of seasonal and climate variations, climate change, surface-water runoff, and evapotranspiration. These processes result in a spatial distribution of water available to percolate through the unsaturated zone beneath the surficial soils as infiltration. Uncertainty in infiltration is a result of uncertainty in soil and rock characteristics, precipitation, and surface topography. The rate of net infiltration and its associated uncertainty are evaluated using the infiltration model for the first 10,000 years following repository closure. For the post-10,000-year period up to geologic stability, the effects of infiltration are implicitly incorporated into the performance assessment by using a distribution for the deep percolation rate that implements requirements of the proposed rule.	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	Seepage monitoring Subsurface water and rock testing
UNB	Unsaturated Zone above the Repository	1.2.02.01.0A Fractures **Included**	Above the repository, the unsaturated zone includes a network of fractures through which the infiltrated water flows principally by gravity. Because of their importance to flow in the unsaturated zone and seepage into emplacement drifts (see FEP 2.2.07.08.0A, Fracture Flow in the UZ), fracturing is incorporated into the site-scale UZ flow model using the dual-continuum approach. Fracturing is also incorporated in the drift seepage model using continuum modeling. Hydrologic properties for the fracture continuum are derived from model calibration to test data, and their associated uncertainties are evaluated with the flow and seepage models.	**ITBC:** Unsaturated Zone Properties Infiltration and Seepage	Subsurface water and rock testing Unsaturated zone testing Subsurface mapping Seepage monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Unsaturated Zone above the Repository	1.3.01.00.0A Climate Change **Included**	Climate change affects the amount and distribution of water that infiltrates into the surficial soils and underlying bedrock. Future climate analyses indicate that the climate at Yucca Mountain will evolve to a warmer and wetter monsoon climate followed by a cooler, wetter glacial-transition climate within the first 10,000 years after disposal. The effects of climate change on groundwater flow in the unsaturated zone above the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the site-scale UZ flow model for the first 10,000 years and for the post-10,000-year period, using a distribution for the deep percolation rate that implements requirements of the proposed rule.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	Subsurface water and rock testing Seepage monitoring
UNB	Unsaturated Zone above the Repository	1.4.01.01.0A Climate Modification Increases Recharge **Included**	Future climate change significantly affects the amount and timing of precipitation and net infiltration into the UZ. The net effect of climate change after repository closure is to increase the amount of water that can infiltrate and percolate through the unsaturated zone as recharge to the water table. The climate effect on unsaturated zone flow above the repository has been directly included in the site-scale UZ flow model by using variable infiltration rates for each of three climates for the first 10,000 years following repository closure: present-day, monsoon, and glacial-transition. After that and through the period of geological stability (as proposed by 40 CFR 197 [DIRS 184076]), the effect of climate modification on percolation and recharge is incorporated into the site-scale UZ flow model using a distribution for the deep percolation rate that implements requirements of the proposed rule. The effect of climate change is also included in the drift seepage model through percolation fluxes at the PTn/TSw interface predicted by the site-scale UZ flow model. Climate modification has a direct and strong effect on the infiltration rate as a boundary condition to the site-scale UZ flow model.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	Subsurface water and rock testing Seepage monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Unsaturated Zone above the Repository	2.1.08.01.0A Water Influx at the Repository **Included**	Influx of liquid water is the same as seepage into the emplacement drifts. Seepage occurs when the downward percolation flux in the host rock is not completely diverted around underground openings by capillary flow processes (FEP 2.2.07.20.0A). The principal factors that determine the occurrence and magnitude of seepage, in addition to the percolation flux, are the bulk permeability and the capillary strength of the fractured host rock. Uncertainty in these parameters, based on observations from in situ testing, is included in the performance assessment. Representativeness of the seepage parameter distributions used in the performance assessment (SNL 2007 [DIRS 181244], Section 6.6) within the repository host rock is considered important to the capability of the upper natural barrier. Note that effects from rock excavation and committed materials are addressed for other FEPs (1.1.01.01.0B, 2.1.06.04.0A, and 2.1.08.02.0A).	**ITBC:** Unsaturated Zone Properties Infiltration and Seepage Properties of the Host Rock Unit	Unsaturated zone testing Seepage monitoring
UNB	Unsaturated Zone above the Repository	2.2.03.01.0A Stratigraphy **Included**	The stratigraphic sequence of unsaturated strata defines the hydrologic characteristics along flowpaths between the surface and the repository horizon. This sequence of both welded and nonwelded tuffs affects the transient propagation of infiltration pulses and tends to spatially redistribute the locally variable infiltration rates. This sequence has been directly included in the site-scale UZ flow model, which also generates percolation fluxes that are used in the seepage and seepage chemistry analyses. Stratigraphy forms the basic framework for the modeling and analysis of rock properties, mineral distributions, faulting and fracturing, hydrologic flow, and radionuclide transport. For the unsaturated zone above the repository, stratigraphy provides the framework in which the percolation processes occur. The quantity as well as the spatial and temporal variations in percolation flux will directly affect (1) the amount of water flowing into waste emplacement drifts, and (2) moisture conditions and the corrosion environment of waste packages within the drifts.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	Subsurface mapping Unsaturated zone testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Unsaturated Zone above the Repository	2.2.03.02.0A Rock Properties of Host Rock and Other Units **Included**	Rock properties, such as fracture capillarity and permeability, significantly affect the amount of flow diversion for a given percolation flux around emplacement drifts. Rock properties and their associated variabilities have been incorporated into both the site-scale UZ flow model and the drift seepage models. The UZ flow model uses layer-specific hydrologic properties and fault properties to represent the large-scale heterogeneity, sufficient to represent site-scale flow processes. Hydrologic property differences at stratigraphic interfaces contribute to lateral diversion of percolation flux in the stratigraphic units above the repository. In addition, the drift seepage model uses stochastic parameter distributions to capture intermediate-scale flow focusing effects, and small-scale heterogeneity and other uncertainties in fracture permeability and capillarity. Key rock properties such as fracture permeability control percolation in the unsaturated zone and seepage into emplacement drifts.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	Subsurface mapping Unsaturated zone testing Seepage monitoring
UNB	Unsaturated Zone above the Repository	2.2.07.02.0A Unsaturated Groundwater Flow in the Geosphere **Included**	Unsaturated groundwater flow defines the flow fields including distribution of percolation flux in space and time, the seepage into emplacement drifts, and the PTn/Tsw boundary fluxes.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	Unsaturated zone testing Seepage monitoring Subsurface water and rock testing
UNB	Unsaturated Zone above the Repository	2.2.07.08.0A Fracture Flow in the UZ **Included**	Above the repository, the infiltrated water flows principally by gravity through networks of fractures in the TCw and TSw units in the unsaturated zone. Fracture flow dominates in the welded units with a high density of interconnected fractures. In the nonwelded PTn unit, the relatively high matrix permeability/porosity and the relatively low fracture density cause the flow to be matrix-dominated. Within the repository footprint, fracture flow accounts for more than 90% of total water percolation flux at the repository horizon.	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	Subsurface mapping Unsaturated zone testing Seepage monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
UNB	Unsaturated Zone above the Repository	2.2.07.20.0A Flow Diversion Around Repository Drifts **Included**	Downward percolation flux in the near-field host rock tends to be diverted around drift openings by capillary flow processes. When the flux is not fully diverted, then seepage results. The effectiveness of diversion is a function of the percolation rate, the permeability and capillarity strength of the host rock, and the opening geometry. The key parameters affecting flow diversion, and the associated parameter uncertainties, are included in the performance assessment through the seepage models (BSC 2004 [DIRS 171764], Section 6.3.2). Flow diversion is an important function of the upper natural barrier, so the key parameters of this FEP are considered important to barrier capability. The parameters affecting flow diversion, and the associated parameter uncertainties, have been obtained from the analyses of liquid release tests performed at several locations at the Exploratory Studies Facility and included in the seepage models.	**ITBC:** Unsaturated Zone Properties Infiltration and Seepage Properties of the Host Rock Unit	Subsurface mapping Unsaturated zone testing Seepage monitoring
EBS	Emplacement Drift	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to cause seismically induced rockfall that changes the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Sections 6.3.1.2 and 6.4.2.2) and changes the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). A change in the cross section of the emplacement drifts can alter the seepage into the drifts, and the presence of rockfall about the drip shield can alter the mechanical response and temperature time history of the EBS components. The response of the emplacement drift configuration and processes to vibratory ground motion is ITBC.	**ITBC:** Properties of the Host Rock Unit Characterization of Seismic Events **Non-ITBC:** Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Characterization of Seismic Events	Seismicity monitoring Construction effects monitoring Drift inspection

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Emplacement Drift	1.2.03.02.0B Seismic-induced Rockfall damages EBS Components **Excluded**	Seismically induced rockfall in the emplacement drifts can change the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Section 6.3.1.2), and can change the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). For example, a change in the cross section of the emplacement drifts can alter the seepage into the drifts. As a second example, the presence of rockfall around the drip shield can alter the mechanical response and temperature time history of the EBS components. The response of the emplacement drift configuration and processes to seismically induced rockfall is ITBC.	**ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration **Non-ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Seismic Events	Seismicity monitoring Construction effects monitoring Drift inspection
EBS	Emplacement Drift	1.2.03.02.0C Seismic-induced Drift Collapse Damages EBS Components **Included**	Seismically induced drift collapse in the emplacement drifts can change the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Section 6.4.2.2), and can change the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). For example, a change in the cross section of the emplacement drifts can alter the seepage into the drifts. As a second example, the presence of rubble around the drip shield can alter the mechanical response and temperature time history of the EBS components. The response of the emplacement drift configuration and processes to seismically induced drift collapse is ITBC.	**ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration **Non-ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Seismic Events	Seismicity monitoring Construction effects monitoring Drift inspection
EBS	Emplacement Drift	1.2.03.02.0D Seismic-induced Drift Collapse Alters In-drift Thermal-Hydrology **Included**	The thermal-hydrologic effects from drift collapse induced by a seismic event have been included in the evaluation of barrier capability. These effects include an increase in the temperature and an increase in the probability and magnitude of seepage (SNL 2008 [DIRS 184433], Section 6.3.17[a]; SNL 2007 [DIRS 181244], Section 6.4; BSC 2004 [DIRS 166107], Section 6.3). The increase in temperature is due to the insulating effect from rubble surrounding the drip shield. The increase in seepage is due to the irregular shape of a collapsed drift, which degrades the capability of the drift wall to act as a capillary barrier to the inflow of seepage. The response of the in-drift thermal-hydrology to seismic-induced drift collapse is ITBC.	**ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Properties of the Host Rock Unit Infiltration and Seepage **Non-ITBC:** Characterization of Igneous Events	Seismicity monitoring Corrosion testing Construction effects monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Emplacement Drift	2.1.08.07.0A Unsaturated Flow in the EBS **Included**	Unsaturated flow occurs through the features of the EBS due to seepage or condensation processes. The nature of this flow has been included in the abstractions for flow and transport through the EBS features (SNL 2007 [DIRS 177407], Sections 5 and 6). Unsaturated flow limits advective transport of radionuclides and other chemical species, for example under intact drip shields, and facilitates isolation of water from the waste packages and waste forms. Accordingly, the parameters that describe and control unsaturated flow conditions are considered to be ITBC.	**ITBC:** Infiltration and Seepage Properties **Non-ITBC:** Unsaturated Zone Properties Properties of the Host Rock Unit	Thermally accelerated drift in-drift environment monitoring
EBS	Emplacement Drift	2.1.09.01.0A Chemical Characteristics of Water in Drifts **Included**	Chemical characteristics of water in the drift are affected by the chemistry of incoming water (from seepage, condensation, or wicking), evaporation, temperature, and interaction with CO_2 in the drift environment. These chemical characteristics affect the likelihood of potential degradation, deterioration, and alteration of the other EBS components, as well as affecting the transport characteristics of any radionuclides released from the waste package to the invert (SNL 2007 [DIRS 177412], Section 6.13). The output of models that describe the in-drift chemical environment, combined with models that describe degradation of the drip shield and waste package, significantly affect the EBS barrier capability.	**ITBC:** Seepage Water Properties In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties In-Drift Thermal Environment Convection, Condensation, and Evaporation **Non-ITBC:** Waste Form Degradation Corrosion Products Properties Invert Materials, Properties, and Configuration	Waste package monitoring Waste form testing Thermally accelerated drift near-field monitoring Thermally accelerated drift in-drift environment monitoring Seepage monitoring Drift inspection Corrosion testing Dust buildup monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Emplacement Drift	2.1.11.01.0A Heat Generation in EBS **Included**	The heat generated by radioactive decay has multiple effects on repository-relevant processes, including degradation, deterioration, and alteration of the EBS. The heat generation in the emplacement drifts affects the timing of the onset of seepage processes and the distribution of in-drift convection and condensation. The heat generation and resultant temperature also affect the water chemistry in the rock and emplacement drifts. Temperature also affects corrosion rates for the drip shield and waste package. The temperature resulting from heat generation also affects the initiation of waste form alteration and radionuclide transport processes dependent on the presence of an aqueous film (SNL 2008 [DIRS 184433], Section 6.2.1[a]; SNL 2007 [DIRS 181648], Executive Summary).	**ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Seepage Water Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat **Non-ITBC:** Invert Materials, Properties, and Configuration Waste Form Degradation Properties of the Host Rock Unit	Thermally accelerated drift near-field monitoring Thermally accelerated drift in-drift environment monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Emplacement Drift	2.1.11.08.0A Thermal Effects on Chemistry and Microbial Activity in the EBS **Included**	The in-drift temperature substantially affects the evolution of the in-drift chemistry, but its impact on microbial activity in the Yucca Mountain environment does not significantly impact barrier capability. Environmental factors will severely limit microbial activity in the repository (see FEP 2.1.13.03.0A). The effects from microbial activity on the in-drift chemical environment are not significant (see FEP 2.1.10.01.0A). The potential for microbially influenced corrosion of the waste package outer barrier is included, although it does not significantly impact barrier capability (FEP 2.1.03.05.0A).	**ITBC**: In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form Degradation Radionuclide Inventory and Source-Term Properties Corrosion Products Properties	Thermally accelerated drift in-drift environment monitoring Thermally accelerated drift near-field monitoring Corrosion testing Waste form testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Emplacement Drift	2.2.08.12.0A Chemistry of Water Flowing into the Drift **Included**	The chemistry of the seepage water is evaluated in the near-field chemistry model and in supporting thermal-hydrologic-chemical models. These models have evaluated the range of expected water composition in the host rock, and how these waters change in response to repository heating. Seepage composition can affect corrosion of the waste package outer barrier if the water contacts the waste package when other conditions, such as temperature, promote initiation of localized corrosion. In addition, seepage composition and evaporative evolution in the drift environment can affect the transport of dissolved and colloidal radionuclides in the invert.	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Seepage Water Properties Radionuclide Inventory and Source-Term Properties Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	Seepage monitoring Thermally accelerated drift near-field monitoring Thermally accelerated drift in-drift environment monitoring Corrosion testing
EBS	Drip Shield	1.2.03.02.0C Seismic-Induced Drift Collapse Damages EBS Components **Included**	This FEP deals with rubble rock fall and drift collapse. Large block rock fall is dealt with separately under FEP 1.2.03.02.0B. Seismically induced drift collapse in the emplacement drifts has the potential to fail the drip shields as barriers to flow and as barriers to rockfall. Rupture of the drip shield plates or buckling of the sidewalls of the drip shield can occur if the static load from lithophysal rubble plus the dynamic load during a seismic event exceed the ultimate plastic load capacity of the plates or of the drip shield framework (SNL 2007 [DIRS 176828], Section 6.8). The drip shield response to drift collapse is therefore ITBC.	**ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration Characterization of Seismic Events	Drift inspection Corrosion testing Construction effects monitoring Seismicity monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Drip Shield	2.1.03.01.0B General Corrosion of Drip Shields **Included**	General corrosion rates of titanium in the range of likely environmental conditions are low during the regulatory period. This process has been included in models of drip shield degradation (SNL 2007 [DIRS 180778], Section 6). The slow degradation rate of the drip shield by this process is an important beneficial characteristic of the drip shield that substantially reduces the release of radionuclides and their contact with water.	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Seepage Water Properties Drip Shield Materials, Properties, and Configuration	Corrosion testing Corrosion testing of thermally accelerated drift samples
EBS	Drip Shield	2.1.03.02.0B Stress Corrosion Cracking of Drip Shields **Excluded**	Titanium has been shown to be potentially susceptible to the initiation of stress corrosion cracking under likely emplacement drift environments in the presence of mechanical damage from seismic response and rockfall. Although such cracks may be initiated, their propagation and characteristics (size and morphology) are such that they do not allow the advective flow of water through them. Even if some limited flow of water did occur through the cracks, the openings are expected to fill with corrosion products and evaporative mineral deposits, precluding advective flow (FEP 2.1.10.03.0B). Although it is possible that stress corrosion cracking of the titanium drip shield could occur in the regulatory period after closure, the presence of such cracks is insufficient to affect the capability of the drip shield to significantly reduce the amount of water that could directly contact the waste package. Although this process has been excluded from the performance assessment, the lack of significant degradation by this process is an important characteristic of the drip shield feature of the EBS.	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Drip Shield Materials, Properties, and Configuration	Corrosion testing Corrosion testing of thermally accelerated drift samples

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Drip Shield	2.1.03.03.0B Localized Corrosion of Drip Shields **Excluded**	Titanium is unlikely to be susceptible to localized corrosion over a wide range of expected emplacement drift environmental conditions. Uncertainty in the initiation of localized corrosion using corrosion potentials and critical repassivation potentials (whether by pitting or crevice corrosion) has been considered in the assessment of the likelihood of localized corrosion of the drip shield and excluded from the TSPA. The lack of significant degradation by this process is an important characteristic contributing to the barrier capability of the drip shield feature of the EBS.	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Drip Shield Materials, Properties, and Configuration	Corrosion testing Corrosion testing of thermally accelerated drift samples
EBS	Drip Shield	2.1.03.10.0B Advection of Liquids and Solids through Cracks in the Drip Shield **Excluded**	Although cracks may occur in the drip shield (primarily as a result of stress corrosion cracks), the size of these cracks is sufficiently small (on the order of 0.1 to 0.2 mm) and the morphology of these cracks is sufficiently tight that advective flow of water through the cracks is not expected. Although this process has been excluded from the TSPA, the lack of significant advection through cracks in the drip shield is an important characteristic of the drip shield barrier capability. The lack of advection through these cracks limits or prevents localized corrosion of the waste package, which might otherwise occur under certain conditions.	**ITBC:** Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties	Corrosion testing
EBS	Drip Shield	2.1.06.06.0A Effects of Drip Shield on Flow **Included**	The importance of the diversion performance of the drip shield is directly related to the lack of significant degradation, or to the slow rate of degradation, and the limited potential for liquid advection through stress corrosion cracks. The flow diversion, when combined with the lack of advection through the waste package, results in only the potential for diffusive releases from the waste form and waste package if the waste package has degraded features (SNL 2007 [DIRS 181648], Section 6.2.1; SNL 2007 [DIRS 177407], Section 6.3.3). The drip shield also limits or prevents localized corrosion of the waste package, which might otherwise occur under certain conditions.	**ITBC:** Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties Seepage Water Properties In-Drift Thermal Environment Convection, Condensation, and Evaporation	Seepage monitoring Corrosion testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Drip Shield	2.1.07.05.0B Creep of Metallic Materials in the Drip Shield **Excluded**	Although creep of titanium may occur, the rates are sufficiently low in repository-relevant conditions that no significant degradation of the drip shield occurs, even for long durations, so it is excluded from TSPA. It is ITBC because the design and handling must remain as analyzed for the number of early failures to stay insignificant.	**ITBC:** Drip Shield Materials, Properties and Configuration **Non-ITBC:** In-Drift Thermal Environment	Corrosion testing
EBS	Drip Shield	2.1.09.28.0B Localized Corrosion on Drip Shield Surfaces due to Deliquescence **Excluded**	The potential for salts to deliquesce on the drip shield surface has been evaluated. Although the potential for salts to deliquesce exists, the effects of such deliquescence are insignificant due to the lack of initiation of localized corrosion on the drip shield for a wide range of environmental conditions, including deliquescent brine conditions. The lack of significant degradation by this process is an important characteristic contributing to the barrier capability of the drip shield feature of the EBS.	**ITBC**: Drip Shield Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Seepage Water Properties	Dust buildup monitoring Corrosion testing Thermally accelerated drift in-drift environment monitoring
EBS	Waste Package	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the waste packages from waste package-to-waste package impacts and from waste package-to-pallet impacts that may occur during a seismic event. These impacts may cause plastic deformation of the waste packages outer corrosion barrier (OCB) or cause rupture/puncture of the OCB. Plastic deformation of the OCB may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. Once the OCB is breached by a crack network, diffusive releases of radionuclides can occur from the waste packages. Once the OCB is ruptured or punctured, advective release of radionuclides can occur from the waste packages. The response of waste packages to vibratory ground motion is important for barrier capability.	**ITBC:** Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Characterization of Seismic Events **Non-ITBC:** Pallet Materials, Properties, and Configuration Properties of the Host Rock Unit	Seismicity monitoring Construction effects monitoring Corrosion testing Drift inspection

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Package	2.1.03.01.0A General Corrosion of Waste Packages **Included**	General corrosion rates for Alloy 22, for a range of likely environmental conditions in the emplacement drifts, are so low that failure by general corrosion is not predicted for several hundred thousand years. Uncertainty in these corrosion rates has been included in the model. The slow degradation rate of Alloy 22 under expected repository conditions is an important beneficial characteristic of the waste package feature. Although the stainless steel inner shell of the waste package provides resistance to general corrosion processes, this component of the waste package has been conservatively modeled to provide no delay of penetration of the waste package once the waste package Alloy 22 outer barrier has been breached (SNL 2007 [DIRS 178519], Section 1).	**ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Seepage Water Properties	Corrosion testing Corrosion testing of thermally accelerated drift samples
EBS	Waste Package	2.1.03.02.0A Stress Corrosion Cracking of Waste Packages **Included**	Stress-induced corrosion cracking of Alloy 22 may occur as a result of mechanical degradation following seismic events. Such stress cracks are sufficiently small and tight to allow only the diffusive transport of radionuclides through the cracks (SNL 2007 [DIRS 181953], Section 6.8.6). The lack of significant stress corrosion cracking of the waste package, except in the event of seismically induced damage, is an important characteristic of the waste package.	**ITBC:** In-drift Chemical Environment In-drift Thermal Environment Waste Package Materials, Properties, and Configuration	Corrosion testing Corrosion testing of thermally accelerated drift samples

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Package	2.1.03.03.0A Localized Corrosion of Waste Packages **Included**	Localized corrosion mechanisms on the waste package surface are dependent on the thermal-hydrologic and thermal-chemical environment on the waste package surface. Initiation of localized corrosion is possible in those cases where the drip shield has degraded sufficiently that incoming seepage is allowed to contact the waste package, and certain antecedent temperature and chemical environment conditions exist, such as in the fault displacement modeling case of the seismic scenario class. In this case, waste packages that are susceptible to localized corrosion will have already experienced mechanical damage failure (SNL 2007 [DIRS 178519], Section 6.4.4). The general absence of the conditions necessary to initiate localized corrosion is an important beneficial characteristic on the waste package.	**ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Seepage Water Properties	Corrosion testing Corrosion testing of thermally accelerated drift samples
EBS	Waste Package	2.1.03.10.0A Advection of Liquids and Solids through Cracks in the Waste Package **Excluded**	Cracks in the waste package, which may result from mechanical degradation associated with seismic activity, are of insufficient size to allow significant advective flux of water, and therefore this process is excluded from the performance assessment. However, cracks can allow moisture to enter the waste package via diffusion in sufficient amounts to initiate degradation and alteration of the materials and waste forms inside the waste package. In addition, diffusive transport through these cracks is the dominant transport process for radionuclides released from the waste, for cases in which the drip shield continues to perform its diversion function. The lack of significant advection through cracks in the waste package is an important beneficial characteristic of the waste package feature.	**ITBC:** Infiltration and Seepage Properties Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	Corrosion testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Package	2.1.09.28.0A Localized Corrosion on Waste Package Outer Surface due to Deliquescence **Excluded**	The potential for salts to deliquesce on the waste package outer surface has been evaluated. Although the potential for salts to deliquesce exists, the effects of such deliquescence have been determined to be insignificant to performance, and localized corrosion processes are not expected to be initiated. Even if localized corrosion was initiated, due to the limited volumes, it is likely that the process would not propagate through the waste package outer surface. The lack of significant degradation by this process is an important characteristic contributing to the barrier capability of the drip shield feature of the EBS.	**ITBC:** Waste Package Materials, Properties, and Configuration Seepage Water Properties In-Drift Chemical Environment **Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation	Corrosion testing Corrosion testing of thermally accelerated drift samples Dust buildup monitoring Waste package monitoring
EBS	Cladding	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	This FEP does not consider naval SNF cladding. FEP 2.1.02.25.0B (Naval SNF Cladding) deals with Navy cladding separately. Seismic effects are included in the seismic ground motion modeling case of the seismic scenario class. Except for naval SNF cladding, no credit is taken for cladding integrity in the TSPA. However, cladding provides barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. The core and control parameter characteristics identified are not considered to be ITBC because this barrier feature/component is not included in TSPA.	**ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Seismic Events **Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Properties of the Host Rock Unit	None. Conservatively treated in PA because the capability is not realized.
EBS	Cladding	2.1.02.25.0B Naval SNF Cladding **Included**	The degradation characteristics of the naval SNF cladding have been assessed separately from the CSNF cladding. These results are contained in a classified document and have been determined to be important to barrier capability.	**ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	Assessment of the naval SNF cladding is provided in the naval classified technical support document. No PC activity required.

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Form and Waste Package Internals	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the waste forms and waste package internals from waste package-to-waste package impacts and from waste package-to-pallet impacts that may occur during a seismic event. These impacts may cause axial and lateral accelerations of the spent fuel assemblies that are large enough to buckle the waste form and the waste package internals. These impacts may also cause plastic deformation of the waste package OCB. Plastic deformation of the OCB may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. Once the OCB is breached by a crack network, corrosion of the waste form and waste package internals will compromise their capacity to support structural loads and to support the waste form during vibratory ground motion. The response of the waste form and waste package internals to vibratory ground motion is ITBC.	**ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Properties of the Host Rock Unit Characterization of Seismic Events **Non-ITBC:** Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Committed materials	Seismicity monitoring Construction effects Monitoring Corrosion testing
EBS	Waste Form and Waste Package Internals	2.1.02.01.0A DSNF Degradation (alteration, dissolution, and radionuclide release) **Included**	This FEP addresses the degradation, alteration, and dissolution of the DOE SNF waste form, as well as the effects of phase separation, oxidation of spent fuels, selective leaching, and the effects on DOE SNF canister degradation. These processes can influence the mobilization of radionuclides.	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	Waste form testing Corrosion testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Form and Waste Package Internals	2.1.02.02.0A CSNF Degradation (Alteration, Dissolution, and Radionuclide Release) **Included**	This FEP addresses alteration, degradation, and dissolution of the waste form. These processes can influence the mobilization of radionuclides (BSC 2004 [DIRS 169987], Sections 6.1 and 6.2). This is the principal FEP describing the structure, composition, and degradation of the CSNF waste form.	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	Waste form testing Corrosion testing
EBS	Waste Form and Waste Package Internals	2.1.02.03.0A HLW Glass Degradation (Alteration, Dissolution, and Radionuclide Release) **Included**	This FEP addresses alteration and degradation of the waste form. These processes, along with phase separation, congruent dissolution, precipitation of silicates, co-precipitation of other minerals, and selective leaching, substantially impact the mobilization of radionuclides.	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	Waste form testing Corrosion testing
EBS	Waste Form and Waste Package Internals	2.1.02.09.0A Chemical Effects of Void Space in Waste Package **Included**	Chemistry effects of voids in the waste package internals are included in models of in-package chemistry (SNL 2007 [DIRS 180506], Section 6.3.1.1). In-package chemistry contributes significantly to the solubility characteristics of radionuclides, the degradation of waste package internals and waste form, and the transport behavior of radionuclides released from the waste form.	**ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Corrosion Products Properties In-Package Chemical Environment **Non-ITBC:** In-Package Thermal Environment Waste Form Degradation	Waste form testing Corrosion testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Form and Waste Package Internals	2.1.09.01.0B Chemical Characteristics of Water in Waste Package **Included**	The chemical characteristics of the water in contact with the waste package internals, including void spaces, and the waste form, affect the degradation characteristics of the waste form, the solubility of radionuclides in the dissolved phase, and the stability of colloidal particles. These chemical effects are significant in affecting release of low solubility radionuclides (e.g., ^{90}Sr, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) and radionuclides that may be released attached to colloidal particles (e.g., ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) (SNL 2007 [DIRS 180506]). These characteristics, as well as uncertainty in the in-package chemistry, in particular the ionic strength and pH, which have the most significant effect on these coupled processes, are included in the in-package chemistry and solubility models (SNL 2007 [DIRS 180506], Sections 6.10.8 and 8.1).	**ITBC:** Waste Package Materials, Properties, and Configuration Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment Radionuclide Inventory and Source-Term Properties Corrosion Products Properties **Non-ITBC:** In-Package Thermal Environment	Seepage monitoring Waste form testing Corrosion testing
EBS	Waste Form and Waste Package Internals	2.1.09.02.0A Chemical Interaction with Corrosion Products **Included**	Aqueous chemical conditions inside waste packages are strongly influenced by interaction with the products from chemical degradation of steels, waste forms, and other materials there (SNL 2007 [DIRS 180506]). Corrosion products constitute the medium for transport of radionuclides within the package by advection or diffusion. Sorption and other types of reactions may retard or sequester certain radionuclides in corrosion products (SNL 2007 [DIRS 177407]). Outside the waste package, no credit is taken for corrosion products affecting transport of radionuclides.	**ITBC:** In-Package Chemical Environment Waste Form/Package Internals Materials, Properties, and Configuration Corrosion Products Properties **Non-ITBC:** Waste Form Degradation	Waste form testing Corrosion testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Form and Waste Package Internals	2.1.09.04.0A Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS **Included**	Solubility limits of low solubility dissolved radionuclides significantly affect the amount of these radionuclides that may be released from the waste form through the other EBS features (SNL 2007 [DIRS 180506]). The more soluble the radionuclide, generally the greater the mass flux of that radionuclide that will be released by diffusive or advective release mechanisms from the waste form. Uncertainty in these solubilities and the effects of waste package internal chemistry variability and uncertainty have been included in the models of waste form release (SNL 2007 [DIRS 177418], Section 8.1).	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	Waste form testing Corrosion testing
EBS	Waste Form and Waste Package Internals	2.1.09.05.0A Sorption of Dissolved Radionuclides in EBS **Included**	Degradation of waste package internals (e.g., stainless steel) can produce significant quantities of iron/chromium/nickel oxide corrosion products. These materials can have high specific surface area, and high affinity for sorption of certain radionuclides released from the waste forms (SNL 2007 [DIRS 180506]). Such sorption can significantly attenuate the mass flux of radionuclides released from the waste package.	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties	Seepage monitoring Waste form testing Corrosion testing
EBS	Waste Form and Waste Package Internals	2.1.09.07.0A Reaction Kinetics in Waste Package **Included**	Reaction kinetics limit the transport of a host of radionuclides and are implicitly accounted for in the in-package chemistry model, the dissolved concentrations model, and the EBS radionuclide transport abstraction. The parameter characteristics associated with this process substantially impact the transport of radionuclides from the waste form.	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties	Waste form testing Corrosion testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Form and Waste Package Internals	2.1.09.08.0A Diffusion of Dissolved Radionuclides in EBS **Included**	Diffusion is an important transport mechanism for dissolved radionuclides from the waste form surface to the waste package internals and then through the degraded waste package to the invert. Diffusion is controlled by the degree of degradation of the waste package and its internals, and the hydrologic characteristics within the waste package, which in turn are functions of the type of waste. The diffusive transport is conservatively specified to occur through a continuous water film on the surfaces of the EBS features (SNL 2007 [DIRS 177407], Section 6.3.4).	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration **Non-ITBC:** Waste Form Degradation Corrosion Products Properties	Corrosion testing Corrosion testing of thermally accelerated drift samples Waste form testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
EBS	Waste Form and Waste Package Internals	2.1.09.08.0B Advection of Dissolved Radionuclides in EBS **Included**	Advection is an important transport mechanism for dissolved radionuclides from the waste form surface to the waste package internals and then through the degraded waste package to the invert. Advection is controlled by the degree of degradation of the waste package and its internals, and the hydrologic characteristics within the waste package, which in turn are functions of the type of waste. The conditions required for advective transport through a waste package are less likely to occur than those conditions required for diffusion. However, when advective transport through the waste package does occur, its consequences are more significant compared to that from diffusion mechanisms because of the amount of water involved. Therefore, advection through the waste package is identified as ITBC.	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration **Non-ITBC:** Waste Form Degradation Corrosion Products Properties	Corrosion testing Corrosion testing of thermally accelerated drift samples Waste form testing
EBS	Waste Package Pallet	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the emplacement pallets from waste package-to-pallet impacts that may occur during a seismic event. These impacts may deform or even crush the emplacement pallets once general corrosion of Alloy 22 reduces the thickness of the cradles that support the waste package. The impact loads may also fail the stainless steel connector rods in the pallet, allowing the two cradles to move independently during a seismic event. While the cradles remain intact and can support the waste package above the invert, the presence of the pallet can delay diffusive releases of radionuclides from the waste package to the invert, thereby contributing to barrier capability.	**ITBC:** Emplacement Pallet Materials, Properties, and Configuration Properties of the Host Rock Unit Characterization of Seismic Events	Seismicity monitoring Construction effects monitoring Corrosion testing Drift inspection

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Unsaturated Zone Below the Repository	1.2.02.01.0A Fractures **Included**	Fractures below the repository still conduct the majority of the percolation flux through the unsaturated zone, although the low-matrix-permeability zeolitic rocks of the CHn cause increased lateral diversion toward the faults, and the vitric CHn is dominated by matrix flow. The fractures have a significant effect on the rate of radionuclide transport through the unsaturated zone through their influence on transport properties. Important fracture-related transport processes/properties include fracture permeability, porosity, frequency, active fracture model, matrix diffusion coefficient, sorption, and colloid filtration (SNL 2007 [DIRS 184614], Sections 6.2.4 and 6.1.2, Table 4.1-1; SNL 2007 [DIRS 177396], Section 6.2.4).	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	1.2.02.02.0A Faults **Included**	A significant fraction of percolation flux below the repository occurs through faults (on average over 30% at the water table location). In addition, faults are important to unsaturated zone transport because they provide fast pathways for radionuclide transport to the water table (SNL 2007 [DIRS 177396], Section 6.7.5). The Drill Hole Wash Fault and the Pagany Wash Fault act as the main transport conduits from the repository horizon to the water table (SNL 2007 [DIRS 177396], Section 6.8.1.2).	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	1.3.01.00.0A Climate change **Included**	Climate change significantly affects the amount and distribution of water that infiltrates into the surficial soils and underlying bedrock. Future climate analyses indicate that the climate at Yucca Mountain will evolve to a warmer and wetter monsoon climate followed by a cooler, wetter glacial-transition climate within the first 10,000 years after closure, followed by a wetter distribution implemented following requirements from the proposed 40 CFR 197 [DIRS 184076]. The effects of climate change on groundwater flow in the unsaturated zone below the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the site-scale UZ flow model for the first 10,000 years and for the post-10,000-year period, using a distribution for the deep percolation rate that implements requirements of the proposed rule. The effects are then incorporated into the unsaturated zone transport assessment through the use of the flow fields.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Extent of Unsaturated Zone	Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Unsaturated Zone Below the Repository	1.4.01.01.0A Climate modification increases recharge **Included**	The ability of the unsaturated zone to prevent or substantially reduce the rate of movement of radionuclides, is dependent on the percolation flux of water through the unsaturated zone, and the distribution of that flux within the fractured rock mass. This flux is directly dependent on the net infiltration which, in turn, is affected by surficial processes and climate change. Future climate change significantly affects percolation in the unsaturated zone below the repository. The net effect of climate change after repository closure is to increase the amount of water that can infiltrate and percolate through the unsaturated zone as recharge to the water table. The climate effect on the unsaturated zone flow below the repository has been directly included in the site-scale UZ flow model by using variable infiltration rates for each of three climates for the first 10,000 years following repository closure: present-day, monsoon, and glacial-transition. After that and through the period of geological stability as proposed by 40 CFR 197 [DIRS 184076], the effect of climate modification on percolation and recharge is incorporated into the site-scale UZ flow model using a distribution for the deep percolation rate that implements requirements of the proposed rule. The effect of climate change on radionuclide transport in the unsaturated zone is realized by (1) using the predicted future unsaturated zone flow fields (with increased percolation rates), and (2) incorporating the rise in the water table due to recharge and the associated reduction in the unsaturated zone thickness. The increase in percolation flux associated with future climate states significantly reduces the capability of the unsaturated zone feature to limit the rate of radionuclide movement.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Extent of Unsaturated Zone	Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Unsaturated Zone Below the Repository	2.2.03.01.0A Stratigraphy **Included**	Stratigraphy and associated heterogeneity in hydrologic properties can significantly affect unsaturated zone flow processes due to the contribution of faults in conducting flow below the repository and due to the different flow characteristics of the TSw unit, zeolitic and vitric CHn units, and the CFu unit. The zeolitic CHn has low matrix permeability that promotes the development of perched water zones through which lateral diversion can lead water toward the faults. Stratigraphy also affects transport. The zeolitic units tend to have higher sorption capacity that reduces transport rates. In addition, mass transfer between fractures and the tuff matrix plays an important role in transport within the unsaturated zone. Because flow velocity in the matrix is much slower than in fractures, transfer of radionuclides from the fractures to the matrix can significantly retard the overall transport of radionuclides from the repository to the water table.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Unsaturated Zone Flow Properties of the Host Rock Unit	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	2.2.03.02.0A Rock properties of host rock and other units **Included**	Rock properties, such as fracture permeability and sorption coefficient, significantly affect the distribution of percolation flux and radionuclide transport rate in the unsaturated zone. The properties and their associated variabilities have been incorporated into the site-scale UZ flow model and the UZ radionuclide transport model. The unsaturated zone flow model uses layer-specific hydrologic properties and fault properties to represent the large-scale heterogeneity, sufficient to represent site-scale flow processes. Hydrologic property differences at stratigraphic interfaces contributed to some lateral diversion of percolation flux in the stratigraphic units a below the repository. In addition, the UZ radionuclide transport model uses stochastic parameter distributions (e.g., for sorption coefficient, matrix diffusion coefficient, active fracture model α, and fracture porosity) to capture additional effects for transport processes.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Unsaturated Zone Flow Properties of the Host Rock Unit	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	2.2.07.02.0A Unsaturated groundwater flow in the geosphere **Included**	Groundwater flow in the unsaturated zone defines the distribution of percolation flux and is the driving force for radionuclide transport below the repository. Variations in percolation rate and fracture hydrologic properties are the two most important factors that affect transport times through the unsaturated zone.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Unsaturated Zone Below the Repository	2.2.07.07.0A Perched water develops **Included**	Perched water zones exist near the TSw/CHn interface below the repository, as a result of the zeolitization process. These zones lead to lateral diversion of flow in the CHn towards the faults, which act as main pathways for fast flow and transport in the unsaturated zone. Transport analysis shows that transport time to the water table is substantially shorter in regions of the repository underlain by perched water (BSC 2004 [DIRS 170035], Section 6.1.4).	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	2.2.07.08.0A Fracture flow in the UZ **Included**	The unsaturated zone beneath the repository is generally composed of fractured volcanic tuff. The rate of movement of radionuclides in the unsaturated zone is dependent on the flux of water through the fractured rock mass. This flux is distributed between faults, fractures, and the matrix of the host rock and other units in the unsaturated zone. The rate of movement of radionuclides is dependent on the degree of fracture flow, which is variable across the hydrostratigraphic units of the unsaturated zone below the repository. In the absence of significant matrix diffusion, transport is mainly by advection through fractures. The lack of fracture flow in the vitric portions of the Calico Hills unit reduces the advective transport velocity and increases sorption, retarding the movement of radionuclides there.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	2.2.07.09.0A Matrix imbibition in the UZ **Included**	Water and (dissolved and colloidal) radionuclides may be imbibed into the matrix between the flowing fractures. Matrix imbibition affects the distribution of flow between fractures and the matrix in the fractured unsaturated zone. Matrix imbibition is dominant in the Calico Hills nonwelded vitric rock, which substantially slows radionuclide transport.	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing
LNB	Unsaturated Zone Below the Repository	2.2.07.15.0B Advection and dispersion in the UZ **Included**	Advection processes dominate the transport of dissolved and colloidal radionuclides in the UZ transport abstraction model. Additionally, it is noted that dispersive transport processes in the unsaturated zone tend to act on short-term transient releases, which are not expected to be significant for repository performance (BSC 2004 [DIRS 170035], Sections 6.2.5 and 6.3.6.3).	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	Subsurface mapping Unsaturated zone testing Subsurface water and rock testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Unsaturated Zone Below the Repository	2.2.08.08.0B Matrix diffusion in the UZ **Included**	Matrix diffusion causes diffusive migration of dissolved radionuclides from the fractures in the adjacent matrix, along fracture transport pathways through the unsaturated zone. Advective transport through the matrix is slower, and sorption is much greater, than in the fractures, so matrix diffusion can be an effective retardation mechanism, especially for moderately to strongly sorbed radionuclides.	**ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties	Unsaturated zone testing
LNB	Unsaturated Zone Below the Repository	2.2.08.09.0B Sorption in the UZ **Included**	Sorption plays an important role in delaying the movement of most radionuclides through the unsaturated zone. Several radionuclides that are the dominant contributors to the total inventory are significantly retarded in the unsaturated zone when subject to significant matrix diffusion or matrix dominated flow in the vitric Calico Hills. These include ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am. Other radionuclides, such as ^{237}Np, are slightly sorbed. Accordingly, sorption is included in the UZ transport abstraction model using a linear equilibrium sorption (K_d) model. The K_d distributions were developed using various sources of information including laboratory experiments performed under various conditions (time, element concentration, atmospheric composition, particle size, and temperature) with correlations based on consideration of such variables as pH, Eh, water chemistry, rock composition, rock surface area, and radionuclide concentration. The K_d distributions were sampled in the TSPA to account for the effects of uncertainties in pore-water chemistry and mineral surfaces in the UZ. Although it could potentially further delay radionuclide movement through the unsaturated zone, sorption of dissolved or colloidal radionuclides onto fracture surfaces is not considered in the UZ transport abstraction model due to insufficient data.	**ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties	Unsaturated zone testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Saturated Zone	1.2.02.01.0A Fractures **Included**	Fracture characteristics are important to the barrier capability for the saturated zone, because groundwater flow occurs primarily within the fracture network in the volcanic tuff units. The fracture networks in the saturated zone at Yucca Mountain appear to be well-connected over large distances at the scales of interest (hundreds of meters to kilometers). These fracture networks, in turn, control the movement of the dissolved and colloidal radionuclides below the water table. Fracture characteristics (e.g., fracture porosity, flowing interval porosity, and flowing interval spacing) are included in the SZ flow and transport abstraction model using a dual porosity effective continuum approach. Their associated uncertainties are represented through the parameter distributions, which were sampled when generating the breakthrough curves for the TSPA.	**ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	Saturated zone fault zone hydrology testing Saturated zone monitoring
LNB	Saturated Zone	1.2.02.02.0A Faults **Included**	Faults affect the groundwater flow paths, influence the horizontal anisotropy in permeability, and can enhance dispersion by increasing permeability heterogeneities along the saturated zone flow paths. Therefore, faults are incorporated into the SZ flow and transport abstraction model through the use of rock properties, and uncertainties in fault-related parameters such as horizontal anisotropy are also probabilistically included in the model. Faults are considered ITBC for the saturated zone because they may act as preferred conduits or barriers to flow.	**ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	Saturated zone fault zone hydrology testing Saturated zone monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Saturated Zone	1.3.01.00.0A Climate change **Included**	Climate change alters the flux through the saturated zone by increasing the regional recharge and causing the water table to rise (SNL 2007 [DIRS 177391], Section 6.6.4.1). The effect on regional recharge will lead to an increase in the saturated zone groundwater flux between the repository and the accessible environment, which in turn tends to decrease the advective transport time from the repository to the accessible environment for both sorbing and nonsorbing radionuclides that may be released from the unsaturated zone below the repository. This increased flux and potential changes to the groundwater flow paths are conservatively approximated in the SZ flow and transport abstraction model by increasing the specific discharge. This increase causes a significant increase in the movement of radionuclides, which degrades the capability of the saturated zone feature of the Lower Natural Barrier.	**ITBC:** Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone	Subsurface water and rock testing
LNB	Saturated Zone	1.4.01.01.0A Climate modification increases recharge **Included**	The increase in recharge associated with future climate states significantly increases the groundwater flux through the tuff and alluvial water-conducting features, which reduces the effectiveness of the barrier capability of this feature. This effect is incorporated into the saturated zone flow and transport model, and is determined to be ITBC because of its significant contribution to the barrier capability of the saturated zone.	**ITBC:** Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone	Subsurface water and rock testing
LNB	Saturated Zone	2.2.03.01.0A Stratigraphy **Included**	Stratigraphic controls affect groundwater flow paths and rates in the saturated zone. Various parameters significant to the transport of radionuclides through the saturated zone (e.g., effective diffusion, matrix porosity, and bulk density) are dependent on the stratigraphy and heterogeneity of hydrogeologic units. Stratigraphy is included in the performance assessment through the hydrogeologic framework model for saturated zone flow and transport. 27 hydrostratigraphic units and 10 discrete geologic features representing major faults and fractures are represented with specific hydrologic and transport parameters. Stratigraphy is ITBC because of its importance to the determination of groundwater flowpaths and rates of radionuclide movements in the saturated zone.	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	Saturated zone fault zone hydrology testing Saturated zone alluvium testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Saturated Zone	2.2.03.02.0A Rock properties of host rock and other units **Included**	Rock properties for 27 hydrostratigraphic units and 10 discrete geologic features related to faults and factures are explicitly included in the SZ flow and transport abstraction model. Rock properties are considered ITBC because they have a significant effect on the groundwater flowpaths and the rate of radionuclide movement. Some of the important properties include the flowing interval spacing, matrix diffusion, fracture porosity, matrix porosity of the alluvium, retardation properties, matrix porosity of the volcanic units, and effective porosity of the alluvium.	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	Saturated zone fault zone hydrology testing Saturated zone alluvium testing
LNB	Saturated Zone	2.2.07.12.0A Saturated groundwater flow in the geosphere **Included**	Groundwater flow in the saturated zone defines the distribution of flowpaths and flow rates and is the driving force for radionuclide transport from the water table to the accessible environment. Variations in flowpaths and rates along the volcanic tuff and alluvium aquifers units are important factors that affect transport times through the SZ.	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	Saturated zone fault zone hydrology testing Saturated zone alluvium testing Saturated zone monitoring
LNB	Saturated Zone	2.2.07.13.0A Water-conducting features in the SZ **Included**	Water flow in the saturated zone occurs within the fractured tuff units and the alluvium. The groundwater flow rates, radionuclide transport velocities, and radionuclide retardation characteristics of these different water-conducting features are significantly different. In addition to the differences in flow and transport characteristics of the 27 different hydrogeologic units in the saturated zone, the presence of 10 discrete flowing features in the fractured tuff units control the advective velocities and, therefore, transport times from the base of the unsaturated zone to the alluvium. Depending upon their physical properties, these discrete features act as either barriers or conduits to groundwater flow in the saturated zone. In the southern part of the saturated zone model domain near Amargosa Valley, the flow in the alluvium provides a significant reduction in the movement of radionuclides to the accessible environment.	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	Saturated zone fault zone hydrology testing Saturated zone alluvium testing Saturated zone monitoring

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Saturated Zone	2.2.07.15.0A Advection and dispersion in the SZ **Included**	Advection is the principal transport mechanism for both dissolved and colloidal radionuclides in the saturated zone. The advective flux is dependent on the hydrogeologic characteristics of the hydrostratigraphic units and discrete water-conducting features in the saturated zone, as well as the hydraulic gradient through these units and features. Dispersive processes tend to spread transient radionuclide pulses that may be released to the saturated zone (e.g., following the breach of a waste package or the water table rise associated with climate changes). These processes have been included in the saturated zone transport. Advection through the fractures is ITBC because of its importance for determining flow paths and rates of radionuclide movement in the SZ. Dispersion, however, is not ITBC because it has insignificant contributions to radionuclide transport in the saturated zone.	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	Saturated zone fault zone hydrology testing Saturated zone alluvium testing
LNB	Saturated Zone	2.2.08.08.0A Matrix diffusion in the SZ **Included**	Field scale in situ tracer tests at the C-wells validated matrix diffusion as an important transport mechanism in fractured volcanic formations in the saturated zone. This process can be an effective retarding mechanism and is ITBC for the saturated zone. Although field-test data from the Alluvial Testing Complex and the Nye County Early Warning Drilling Program Site 22 also indicate some degree of heterogeneity in the alluvium, no credit is taken for matrix diffusion in the alluvial units based on consideration for conservatism.	**ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties	Saturated zone fault zone hydrology testing Saturated zone alluvium testing

Table A-2[a]. FEPs, Barrier Capability, and PC Activity (Continued)

Barrier	Feature	FEP Number/Name/Status	Effect on Barrier Capability	Core Parameter Characteristic	PC Activity
LNB	Saturated Zone	2.2.08.09.0A Sorption in the SZ **Included**	Sorption plays an important role in delaying the movement of most radionuclides through the saturated zone. Several radionuclides, including those that contribute the most significant fraction of the inventory (for example, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am), are moderately to highly sorbed in the saturated zone. Therefore, sorption is included in the SZ flow and transport abstraction model using a linear equilibrium sorption (K_d) model. The K_d distributions were developed through laboratory experiments under various conditions (time, element concentration, atmospheric composition, particle size, and temperature) with correlations based on consideration of such variables as pH, Eh, water chemistry, rock composition, rock-surface area, and radionuclide concentration. The K_d distributions were sampled in the TSPA to account for the effects of natural variations in pore-water chemistry and mineral surfaces. Although it could potentially further delay radionuclide movement through the saturated zone, sorption of dissolved or colloidal radionuclides onto fracture surfaces is not considered in the SZ flow and transport abstraction model due to insufficient data. Sorption is determined to be ITBC for the saturated zone.	**ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties	Saturated zone fault zone hydrology testing Saturated zone alluvium testing

FEPs Source: SNL 2008 [DIRS 183041].

INTENTIONALLY LEFT BLANK